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Composite Air Brakes: STOPPING THE FASTEST CAR

JULY 2015

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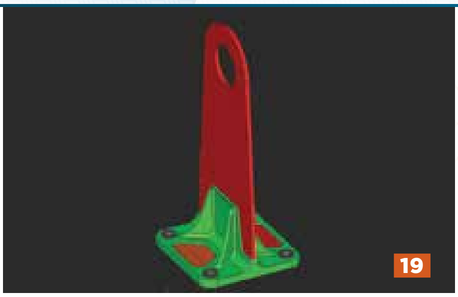
COLUMNS



FEATURES

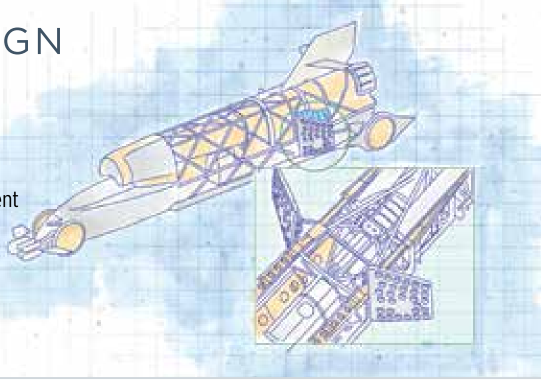
» DEPARTMENTS

» ON THE COVER

When Richard Noble, the current holder of the official World Land Speed Record, attempts to break his own record *and* exceed the mythic and elusive 1,000-mph mark on a 19-km lake bed test track in South Africa this fall, composite air brakes will help his rocket-powered *Bloodhound SSC* racer decelerate safely between and after his two required record runs (see our story on p. 46).

Source / Bloodhound SSC

FOCUS ON DESIGN



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GRAPHIC DESIGNER	Susan Kraus skraus@gardnerweb.com
MARKETING MANAGER	Kimberly A. Hoodin kim@compositesworld.com

CW CONTRIBUTING WRITERS

Dale Brosius	dale@compositesworld.com
Donna Dawson	donna@compositesworld.com
Michael LeGault	mlegault@compositesworld.com
Peggy Malnati	peggy@compositesworld.com
Chris Red	chris@compositesworld.com
Karen Wood	karen@compositesworld.com

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The US Department of Energy's most recently created consortium, the Institute for Advanced Composites Manufacturing Innovation (IACMI), held its first membership meeting in mid-June in Knoxville, KY, US. It gathered together about 350 people, including academicians, suppliers, fabricators, OEMs and government officials. The two-day event was designed to help members lay the groundwork for the consortium's operating principles and outlined in broad terms how IACMI projects and research efforts will be evaluated, vetted and executed. It's still too early to know just how successful IACMI will be, but the mood at the Knoxville meeting was decidedly optimistic.

> We are quickly losing knowledge that is not so easily replaced.

There was one concern brought up by many speakers, and that was *workforce development*, which can mean many things, depending on the context, but in general you can think of it this way: We have too many "old" people and not enough "young" people. Basically, rapidly retiring Baby Boomers are taking with them a ton of composites experience and knowledge that is not easily replaced, because the world — and the US, in particular — is not producing enough graduates qualified to replace them. The shortage of mechanical engineers is particularly acute, but I get the sense that an engineer of any stripe will do, so dire is the need.

There are, of course, many schools that offer excellent composites engineering programs, and several were represented at the IACMI meeting, including the University of Tennessee, the University of Delaware, Michigan State University and the University of Dayton. The big question, then, was this: How do we get more college students interested in engineering, and how do we funnel them towards the composites industry?

Our biggest problem, however, might be that the question we're asking focuses on college students. I suggest that we might be better off thinking more about *high school* students. I say this for two reasons. First it is in high school, not college, that the best and brightest students begin exploring — in earnest — what their skills are and how and where they can be applied. The best high schools and the best parents help such kids along the way with academic and extracurricular programs that offer hands-on experiences and give kids a taste for what could be. For the engineering-minded, this could be a robotics or bridge-building competition, or how about an internship with a local manufacturer? Second, the cost of a college education has become almost universally onerous. Students and parents can't afford a meandering, uncertain college career marked by changes of major that risk elevating the cost. A student who has developed an aptitude in high school and has clear career interests wants to know what his or her path will be through college.

Given this, I think the composites industry has an opportunity. Many high schoolers today have available to them a program called "dual enrollment," where, starting their junior year, they can take classes at a local community college or university, in combination with high school classes. The college classes are typically paid for by the school district, count toward high school graduation and enable the student to earn free, transferable college credit before graduation. Some students actually finish high school with a free associate's degree, or a certificate for a specific skill, which effectively reduces the time required to earn a bachelor's degree.

Could IACMI develop a composites-based, dual-enrollment program that would steer students toward a "pre-engineering" associate's degree? Further, could it combine that with high school internships with composites fabricators to give these kids a taste of the composites life, thereby offering them hands-on experience in a real engineering environment? And finally, could these same kids, after they graduate high school, continue in apprenticeships at composites fabricators while they attend a four-year school and earn that highly coveted engineering degree?

IACMI is composed of the exact mix of composites industry players required to establish such a program, and the geography represented by the consortium members offers a broad area over which we could reach out to students.

It's just an idea, but one with merit. Let me know what you think.

JEFF SLOAN — Editor-In-Chief

Thermosets vs. thermoplastics: Is the battle over?

» Shortly after I moved from Dow Chemical to Fiberite (now part of Cytec Industries) in 1987, I attended a sales meeting where a colleague from Fiberite's parent company, Imperial Chemical Industries (ICI), avowed that, within a decade, thermoplastic composite prepregs would displace thermoset prepregs throughout the aerospace industry. ICI had developed carbon fiber prepregs based on high-temperature PEEK thermoplastic, and the advocate cited advantages, including infinite shelf life, lack of lengthy cure times, easier recyclability and high impact strength. Almost 30 years later, his prediction is unfulfilled: Thermoplastics have made some inroads, on leading edges of some Airbus planes and in various beams, fuselage clips and other structures. And most modern thermoset prepreg systems incorporate thermoplastic polymers at some level to improve damage tolerance. But more than 95% of aerospace prepregs are *still* thermoset.

> I see healthy competition … that makes composites *overall* more competitive with legacy materials.

Full disclosure: I have spent most of my career either promoting or working with thermoset materials. They have attributes that make them attractive for highly stressed parts, including lower processing viscosities for RTM, infusion or prepreg manufacture (which permit high fiber volumes), superior adhesion to fibers (especially true of epoxies), paint and non-composite materials, and high thermal resistance, especially to compressive creep. This enables polyimides to survive the high-temperature zones in jet engines, and phenolic compounds to resist the compressive forces placed on molded brake pistons on a long downhill descent. Composites for wind turbine blades are almost exclusively thermoset, as are the major structures in the Boeing 787 and Airbus A350. To date, carbon fiber-intensive automotive structures, from Italian supercars to the BMW *i3*, feature thermoset matrices. Decades back, the knock on thermosets was that they cured too slowly, but I have seen electrical circuit breakers produced from polyester BMC in multi-cavity injection molds in cycle times of less than 15 seconds. A number of suppliers now offer resins for RTM with the potential for less than 90-second cure.

On the downside, many thermosets have limited shelf lives and there is the risk of spoilage. Whether or not fabricators recognize it, every thermoset mold is a chemical reactor — each part cycle is a polymerization that has to be carefully controlled to avoid exotherm and to achieve the desired state of cure. And if it goes wrong, you cannot grind it up and remold it — at least not easily.

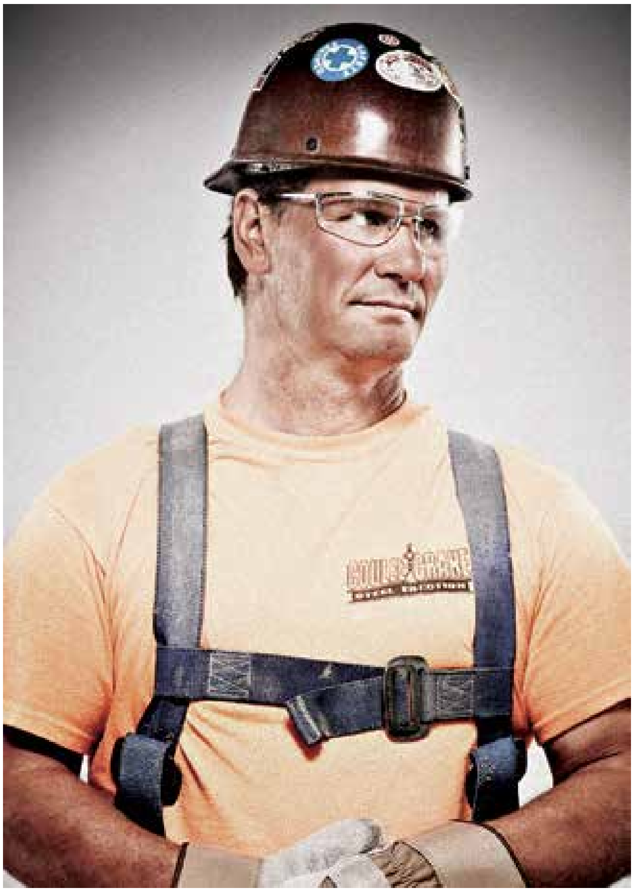
That said, a fair portion of my time was spent competing against thermoplastics for certain applications, especially in the industrial sector, so I became very familiar with thermoplastics and how they are processed. For many years, thermoplastics have enjoyed a reputation as being "easy to process" — pourable, easy to automate, able to melt, solidify and remelt — with properties essentially defined by the material supplier, who had full control of the chemistry. Such materials were recyclable, as long as they were unreinforced or contained only short fibers or mineral fillers. The development of glass mat thermoplastics, which can be compression molded like SMC, and long fiber (typically 6 to 25 mm) pellets, which can be compression or injection molded, opened up new applications, especially in auto components. More recent introductions of continuous unidirectional and fabric-based thermoplastic materials, including carbon fiber versions, based on more economical and easier-to-process resins than PEEK, have positioned thermoplastics squarely against thermoset prepregs.

Recently, I have embraced a more neutral stance, having found numerous applications where thermoplastics might make more sense than thermosets, especially in composite structures. Having a broader palette is very exciting. Two emerging technologies for thermoplastics seem especially appealing. One, structural injection *overmolding*, uses a continuous-fiber structural "backbone," either a flat sheet or a formed/consolidated insert, which is preheated and placed into a mold, behind which reinforced discontinuous materials are injected to form ribs, attachment points and other features (see *CW's* coverage, p. 19). The second is thermoplastic RTM, where the native high viscosity of thermoplastic resins is circumvented by injecting low-viscosity *monomers* into a heated mold containing a fiber preform (similar to thermoset RTM). This is followed by what some call *in-situ polymerization*, resulting in a conventional thermoplastic polymer composite. So far, caprolactam (which forms polyamides) and acrylics show great promise using this technique. (Read more at short.compositesworld.com/InSituPoly).

For decades, thermosets and thermoplastics competed partly by pointing out each other's weaknesses. I don't see as much of that today. Instead, I see healthy competition to develop material systems and processes that make composites *overall* more competitive with legacy materials, providing added value and new avenues to high performance. This is the *right* battlefront, and the one on which our industry — united — needs to prevail. CW

ABOUT THE AUTHOR

Dale Brosius is the chief commercialization officer for the Institute for Advanced Composites Manufacturing Innovation (IACMI), a DoE-sponsored public-private partnership targeting high-volume applications of composites in energy-related industries including vehicles and wind. He is also head of his own consulting company, which serves clients in the global composites industry. His career has included positions at US-based firms Dow Chemical Co. (Midland, MI), Fiberite (Tempe, AZ) and successor Cytec Industries Inc. (Woodland Park, NJ), and Bankstown Airport, NSW, Australia-based Quickstep Holdings. He served as chair of the Society of Plastics Engineers Composites and Thermoset Divisions. Brosius has a BS in chemical engineering from Texas A&M University and an MBA.



Optimum unidirectional compression testing of composites

» Unlike metals and plastics, for which tensile and compressive properties are the same or very similar, unidirectional composites exhibit significantly different mechanical properties, such that both tension and compression testing must be performed.

The relationship between composite tensile and compressive properties is complex. The tensile and compressive modulus of elasticity of unidirectional composites in the fiber direction, E_1, are similar, but differences of 10% or more are commonly observed for carbon/epoxy composites, with the compressive modulus typically lower. The reason for these differences is not well understood. More importantly, however, the tensile and compressive strengths of unidirectional composites in the fiber direction differ greatly, with the compressive strength often significantly lower than the tensile strength. This strength difference results from the different failure modes that occur for each: fiber tensile failure under tension loading vs. fiber micro-buckling under compression loading. This lower compressive strength has important consequences for design, especially in applications that involve flexural loading, in which equal magnitudes of tensile and compressive stress are produced. Unfortunately, it's impossible to predict the unidirectional compressive strength of composites based on fiber and matrix properties, even when tensile strength is known. Thus, compression testing typically is performed in addition to tension testing, and compressive strength is widely considered the more critical property.

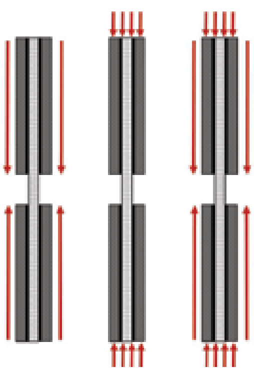


FIG. 1

Specimen loading methods for compression testing.

Source (all images) | Dan Adams

Measuring compressive strength of unidirectional composites is among the most difficult tasks in composites testing. In my January 2015 column (short.compositesworld.com/DandT0615), I summarized the difficulties associated with obtaining the tensile strength of unidirectional composites. These stem from the need to introduce a relatively large load into the specimen and produce failure in the central gage section before failure occurs elsewhere. The same is true for compression testing, and potential specimen buckling/bending make compression testing even more difficult.

To get the most out of the compression test, we must first select a test method. The primary difference among the commonly used methods is the manner in which compressive load is introduced into the specimen (Fig. 1): through shear loading of the tabbed specimen surfaces, through direct compression loading of the specimen ends, or a combination of the two. Regardless of the loading method used, however, tabbed specimens are typically required to achieve the desired results. Typically glass fabric/epoxy printed circuit board material is used for tabbing compression specimens, because it is readily available at low cost, has low stiffness but high strength and can be machined in the same manner as the tested composite material. The most commonly used shear-loaded compression test method is ASTM D 3410[1]. Its test fixture (Fig. 2) includes flat wedge grips that are bolted onto the tabbed surfaces of the specimen, with the assembly placed into mating cavities with wedge-shaped spacers. Alignment rods and linear bearings provide the required alignment between fixture halves. Upon loading, wedge-action gripping is produced in a manner similar to mechanical wedge grips used in tensile testing. For unidirectional composites, the test method specifies a 13-mm wide specimen that is 140 mm long with a 13-mm gage length between the tabs. However, greater specimen widths and gage lengths are permissible, if desired. Although popular in the 1990s, ASTM D 3410 is used less frequently now, due to the large fixture's high cost and the development of other more popular test methods.

End loading of the specimens is another option, but tabs are required here as well to achieve a suitable compression failure in the gage section prior to crushing or splaying at the specimen ends. Additionally, lateral supports are needed to prevent buckling during loading. The most popular end-loaded compression test method is the Modified ASTM D 695 test method (Fig. 2). There is actually no ASTM standard governing this method, but it is defined in the SACMA Recommended Test Method SRM 1R-94[2]. ASTM D 695 specifies a shorter 4.7-mm gage length. This reduces the risk of specimen buckling for a given specimen thickness. But there's a downside: this gage length is too short to permit the use of strain gages or extensometers and, therefore, a separate set of untabbed specimens must be tested for elastic modulus determination.

The third method of loading combines both shear loading and end loading. The Combined Loading Compression (CLC) test method, ASTM D 6641[3], was standardized by ASTM in 2001, and has become the most commonly used compression test method for composites. Its test fixture (Fig. 2) consists of four steel blocks with specimen gripping surfaces coated with tungsten carbide particles. The upper and lower pairs of fixture blocks are bolted »

FIG. 2

Three types of compression test fixture (from left to right): the IITRI compression test fixture (ASTM D 3410), the Modified ASTM D695 test fixture, and the combined loading compression test fixture (ASTM D 6641).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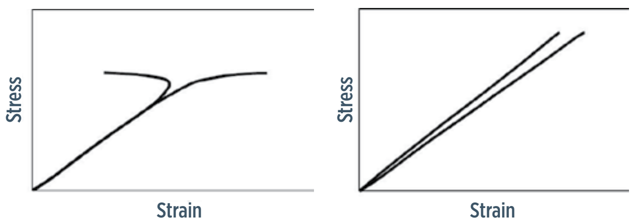


FIG. 3

Buckling, detected using back-to-back strain gages (left) and out-of-plane bending (right) detected using back-to-back strain gages.

to the tabbed specimen, and the assembly is loaded between flat platens. The amount of shear loading is controlled by the torque applied to the bolts that connect the fixture blocks, with a goal of providing sufficient shear loading to avoid crushing at the specimen ends. The specimen dimensions are the same as those specified in ASTM D 3410, although specimen widths up to 30 mm can be accommodated. Advantages of the CLC test method include the relatively small, simple and inexpensive test fixture and the potential to obtain compressive strength test results with less data scatter — a benefit of combined shear and end loading.

Regardless of which test method is selected, the most important consideration is proper specimen design. As in tensile testing, relatively thin specimens are of interest, and bonded tabs are required. Unlike tensile testing, however, the use of a shallow tab taper angle leading into the gage section isn't possible due to the risk of buckling. In general, a thicker specimen and shorter test section are needed to prevent specimen buckling prior to compressive failure. Typically, the shortest practical test section length is selected, and the required minimum specimen thickness to prevent buckling is determined. The two popular ASTM test methods for compression testing of composites, ASTM D 3410 and D 6641, provide an equation for calculating the required specimen thickness, *h*, to prevent bucking of an orthotropic specimen of rectangular cross section, which can be written as

$$\frac{l_g}{0.9069\sqrt{E_x\left(\frac{1}{\sigma^{cu}} - \frac{1.2}{G_{xz}}\right)}},$$

where l_g is the specimen gage length, E_x is the axial modulus of elasticity in the loading direction, G_{xz} is the interlaminar shear modulus, and σ^{cu} is the estimated compressive strength of the specimen. Without having performed tests, values for these three material properties may not be known and, thus, will need to be estimated. Although it might be tempting to neglect the last term in the denominator, $1.2/G_{xz}$, especially when a value of G_{xz} is not readily available, doing so will result in a significant underprediction of the required specimen thickness and the likelihood of specimen buckling. Since this formula estimates the *minimum* specimen thickness to prevent buckling, it's recommended to increase the specimen thickness an additional 10-20% above the calculated value.

Additionally, because buckling cannot be detected visually during testing or from failed specimens, the use of back-to-back strain gages on the specimen faces during testing is required to determine that buckling is not occurring. Buckling results in a sudden divergence of the strains on the specimen faces (Fig. 3), and can significantly reduce the measured compressive strength. Therefore, it is recommended that back-to-back strain gages be used on the initial set of compression tests and that the strains be analyzed before proceeding with additional testing.

Similar to buckling, out-of-plane bending is of concern when compression testing because the variation of strains and stresses across the specimen thickness can lead to reductions in measured compression strength. Bending is commonly traced to problems in specimen fabrication and machining that result in thickness variations. However, bending also can be the result of misalignment in the test fixture or even the testing machine. Similar to buckling, specimen bending may be detected using back-to-back strain gages during testing. However, bending produces a difference in the slopes of the stress vs. strain diagrams from the two gages throughout the test (Fig. 3) rather than a sudden divergence. Let's note, here, that the ASTM standards mentioned above limit bending to less than 10% during the entire test. Interestingly, research results[4] suggest that higher levels of bending (up to 30%) do not significantly reduce compressive strength. Thus, although efforts must be made to minimize misalignments that lead to out-of-plane bending, buckling remains the greater concern. CW

REFERENCES

1 ASTM D3410/D3410M-03(2008), "Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading," ASTM International (W. Conshohocken, PA, US), reapproved 2008 (first issued in 1975).

2 SACMA Recommended Method SRM 1R-94, "Compressive Properties of Oriented Fiber-Resin Composites," Suppliers of Advanced Composite Materials Assn. (Arlington, VA, US), 1994.

3 ASTM D6641/D6641M-09, "Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture," ASTM International (W. Conshohocken, PA,US), 2009 (first issued in 2001).

4 P.M. Wegner and D.F. Adams, "Verification of the Combined Load Compression (CLC) Test Method," Final Report DOT/FAA/AR-00/26, Federal Aviation Admin. (Washington, DC, US), August 2000.

ABOUT THE AUTHOR

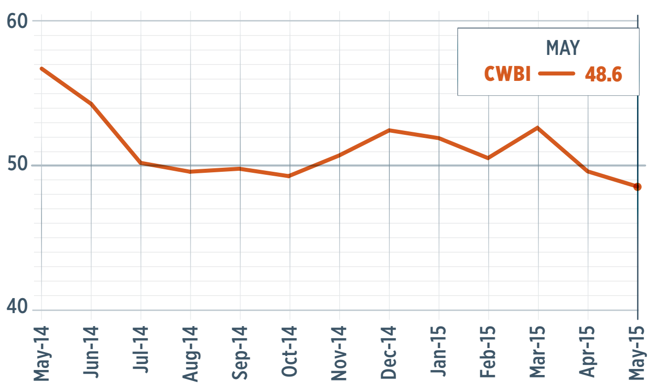
Dr. Daniel O. Adams is a professor of mechanical engineering, the director of the Composite Mechanics Laboratory at the University of Utah, and vice president of Wyoming Test Fixtures, Inc. (Salt Lake City, UT, US). He holds a BS in mechanical engineering and an MS and Ph.D in engineering mechanics. Adams has 35 years of academic/industry experience in the composite materials field and chairs both the Research and Mechanics Div. of ASTM Committee D30 on Composite Materials and the Testing Committee of the Composite Materials Handbook (CMH-17).

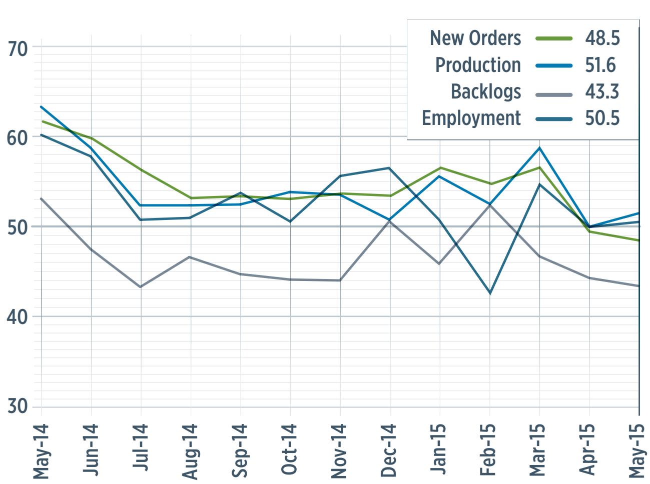
CW Business Index at 48.6 – US industry contraction accelerates

In May 2015, the CompositesWorld Business Index showed an overall reading of 48.6, indicating that the US composites industry contracted for a second month in a row and that the rate of contraction had increased compared with April. The Index was at its lowest level in May since August 2013. Compared with one year earlier, it contracted 14.6%, which was the fastest rate of contraction since December 2012. On an annual basis, the industry contracted in May for the first time since January 2014.

New orders in May contracted for the second month in a row. This ended a US trend of steadily accelerating growth in new orders that had begun back in July 2014. Production increased in May after being flat in April. Generally, production had been stronger than new orders, which had led to contraction in backlogs. Other than in December 2014, the backlog subindex had hovered around 44. Compared with one year earlier, backlogs had performed quite poorly in the five months preceding June 1. The annual rate of change in backlogs had contracted faster in the two preceding months. The trend to that point indicated that capacity utilization in the industry would see slower growth or might contract during the remainder of 2015. Employment in the US composites industry was virtually unchanged in May. Exports had contracted since July 2014. Supplier deliveries lengthened again in May, at about the same rate as they had since January 2014.

A CWBI reading of >50.0 indicates expansion; values <50.0 indicate contraction.





In April and May, material prices increased at a faster rate than they had the previous four months. However, material price increases had been much more subdued over that same six-month period than at any other time since the fourth quarter of 2012. Prices received decreased for the first time since October 2014. The US composites industry's future business expectations subindex had been bouncing up and down quite a bit since the summer of 2014, but in May, that subindex was at its lowest level since October 2014 but also was right at its historical average.

All but the largest US composites fabricators contracted in May. Companies with more than 250 employees showed significant improvement in their May subindex, increasing to 55.5 from 45.8. Facilities with 100-249 employees moved in the opposite direction as their subindex dropped to 49.1 from 64.2. Fabricators with 20-99 employees contracted for the second month in a row. By the end of May, fabricators with fewer than 20 employees had contracted every month but one since June 2014.

The North Central – East was the fastest growing region in May. It had expanded in May for five of the preceding six months. The only other region to grow was the North Central – West, which had done so in six of the previous eight months. The West, which was the fastest-growing region in April, saw its subindex drop to 47.7 from 57.4. The Northeast contracted significantly in April and May and in five of the preceding six months.

Future capital spending plans had been below average in March and April and were, again, in May. Compared with one year earlier, they had contracted more than 20% in each of those months. The annual rate of change had contracted at an accelerating rate during that period. Spending plans in the US composites industry were contracting, in May, at an annual rate of 14.1%. CW

ABOUT THE AUTHOR

Steve Kline, Jr., is the director of market intelligence for Gardner Business Media Inc. (Cincinnati, OH, US), the publisher of *CompositesWorld* magazine. He began his career as a writing editor for another of the company's magazines before moving into his current role. Kline holds a BS in civil engineering from Vanderbilt University and an MBA from the University of Cincinnati.
skline2@gardnerweb.com

SAMPE showcases composites' potential on its conference show floor as others look to realize it with revolutionary approaches to laminate design and mold temperature control … and a new all-composite rotorcraft airframe.

SAMPE Baltimore conference looks back with an eye to the future

Source | SAMPE

SAMPE North America (Covina, CA, US) held its signature conference and exhibition, May 18-21, at the Baltimore Convention Center. The event, hosted by SAMPE's Great Lakes and Baltimore/Washington chapters, as always attracted composite material experts and practitioners from many industries. Given the event's East Coast location and proximity to Washington, DC and US defense interests, the conference keynote speaker was Thomas Russell, director of the U.S. Army Research Laboratory (ARL, Adelphi, MD, US). Taking the long view, Russell said that the ARL is focused on the year 2040 in terms of new technologies and materials. "Our job as a technology community is to make current technologies obsolete," he pointed out. His group is currently researching an array of new concepts, including armor and helmet designs, and he outlined areas he believes require much more work: Among them, better portable power sources for the warfighter, and better weather prediction. Ultimately, Russell indicated, ARL is migrating to an open-campus concept, and is engaging in cooperative agreements with private industry to develop new technology.

SAMPE's Awards Luncheon speaker, Dr. David Robarge, is the US Central Intelligence Agency's chief historian. He had attendees' full and rapt attention, with talk about the A-12 OXCART *Archangel* reconnaissance aircraft. The Mach 3-capable A-12, which replaced the U2 spy plane, came out of a stealth aircraft program started in the late 1950s and declassified in 2007. Robarge described the aircraft's materials, which included composites, as well as its mission history. Notably, he revealed that Area 51 in southern Nevada was where the plane's developmental models were tested to evaluate radar cross-section, and that those activities likely spawned the unidentified flying object (UFO) rumors that persist to this day. Although the A-12 was decommissioned in 1968 after only a small number of missions, a US Air Force variant, the well-known SR-71 *Blackbird*, continued flying until 1989. "The A-12 and SR-71 are still the fastest, highest, jet-powered, piloted aircraft ever flown," claimed Robarge.

Conference themes included structural health monitoring (SHM), nanotechnology, additive manufacturing (see CW's WIP on 3D-printed tooling, p. 22), multifunctional composites, modeling and testing, as well as an update on the DARPA TRUST program, aimed at certification of primary bonded structure (see *CW's* recent TRUST coverage online | short.compositesworld.com/DARPATRUST). Standout papers included the second-place Outstanding Paper Award winner, by Danning Zhang of the University of Delaware. She discussed the issue of reducing voids in thermoplastic laminates by using the interlayer permeability of the prepreg stack during vacuum bag processing. The process must be optimized to allow time for entrapped air to flow before the temperature rise melts the polymer.

The panel "Recent Federal Programs in Composites" assembled a group of US government officials from NASA, the Office of Naval Research (ONR), the Department of Energy, the Air Force Research Laboratory and the ARL. The discussion focused on developing new composite materials and new processing technologies that would improve technology *adoptability*. A key takeaway was a statement by NASA's LaNetra Tate that the Agency wants to see composites used as a primary structure on launch vehicles. And ONR's Bill Nickerson commented that the US Navy is interested in funding better materials. "Durability and performance is the big driver for us," he pointed out, "but when it comes to strength, weight and affordability — there's a big gap of where we are now and where we want to be."

The SAMPE Baltimore exhibit hall yielded some intriguing new products. Find a sampling in the "CW New Products" department on p. 42.

Surface Generation opens two PtFS multi-zone heated mold technology centers

Surface Generation Ltd. (Oakham, Rutledge, UK) announced on May 27 that it has opened two new technology demonstration facilities, after trials demonstrated significant quality improvements in parts created using its novel injection molding techniques. The new centers, in Rutland, UK, and Taipei, Taiwan, will demonstrate Surface Generation's patented Production to Functional Specifications (PtFS)

Source | Surface Generation

heated mold technology to prospective customers. PtFS offers multi-zone mold temperature control, which enables more precise channeling and cooling of molten materials in the mold cavity throughout the process.

The company has trialed the technology for large consumer-electronics and automotive manufacturers, using PtFS with an injection molding machine provided by ENGEL (UK) Ltd. (Royal Leamington Spa, Warwick, UK). Thin- and thick-section tests demonstrated significant process improvements for injection molding applications, including reduction of injection pressures by 75%, making it possible to encapsulate sensitive electronics without damage; resin-rich Class A surfaces with high fiber reinforcement; the possibility for higher fiber-reinforcement levels; elimination of sink marks and warping through highly localized cooling; and less residual stress through directional solidification. The company says that its mold temperature technology makes injection molding much simpler, and that manufacturer interest is growing.

MARINE

Rethinking marine propeller design, with composites


Source | Piranha Propellers

An overarching goal of composites engineering is to transcend "black metal" design — simply replacing metal with a composite. So, Piranha Propellers (Jackson, CA, US) deserves credit for not only developing and manufacturing replacement propellers from long glass fiber-reinforced polymer, but for rethinking the propeller altogether. The result features *interchangeable* blades that can be easily swapped out when damaged or worn. Molded from Complēt MT Series long glass fiber material (60% fiber in a nylon 6 matrix) from PlastiComp (Winona, MN, US), the injection molded blades are designed to absorb impact energy and break, before propagating damage to the propeller shaft, thereby restricting replacement effort and cost to individual blade unit(s), instead of the entire propeller assembly. Piranha owner and founder Brad Stahl says the biggest challenge in marketing the propellers has been convincing customers that composites can do the job. Indeed, says Stahl, "Piranha's Hydrothrust propeller provides 400% more reverse thrust than standard propellers, and twice as much as competing metal props."

CW MONTH IN REVIEW

Notes on newsworthy events recently covered on the *CW* website. For more information about an item, key its link into your browser. Up-to-the-minute news | www.compositesworld.com/news/list.

NASA to test materials on Air Force space plane
The Materials Exposure and Technology Innovation in Space (METIS) experiments on the *X-37B* will build on a previous International Space Station Program.
06/12/15 | short.compositesworld.com/METIS

DLR researchers develop new repair concept for FRPs
The German Aerospace Center's (DLR, Stuttgart, Germany) method involves damage removal by laser, and a bonded patch via local heat and pressure.
06/12/15 | short.compositesworld.com/DLRrepair

Aston Martin creates custom carbon-fiber intensive Vanquish sports cars
The "one of seven" edition features a multi-layered carbon fiber body, with elements of exposed carbon and a satin jet black paint finish.
06/09/15 | short.compositesworld.com/1of7

Matrix Composites to supply part of the Lynx spacecraft's composite body
The chine panels, made for XCOR Aerospace (Mojave, CA, US), are a carbon fiber and epoxy sandwich laminate with a lightweight foam core.
06/08/15 | short.compositesworld.com/Lynxpanels

Haydale creates aerospace unit to focus on composites development
UK-based EPL Composite Solutions, acquired in 2014, becomes Haydale Composite Solutions and launches new graphene-enhanced polymers business unit.
06/08/15 | short.compositesworld.com/Haydale

Spanish investors buy Montefibre Hispania S.A., eventual goal: carbon fiber
Praedium group plans to invest €100 million (US$113 million) to restart Leacril acrylic fiber production, aims for annual 3,000-ton industrial-grade carbon fiber capability.
06/08/15 | short.compositesworld.com/Leacril

Opportunities for composites at AIA 2015
A report on the Composites Pavilion's second appearance at the annual conference of the American Institute of Architects Expo (May 14-16, Atlanta, GA, US).
06/08/15 | short.compositesworld.com/CPatAIA15

Spirit Aeronautics refurbishes aircraft interior with carbon fiber accents
The Cessna *Citation 650* is believed to be the first of its type with the inclusion of carbon fiber accents on black wood stylings during an interior refurbishment.
06/03/15 | short.compositesworld.com/CFAccents

Research team looks to fabricate preforms for composites
New University of Delaware study looks at opportunities and challenges of additive manufacturing for composites processing.
06/03/15 | short.compositesworld.com/UofDPFs

Plastic engine to debut in Norma *M-20* concept car
Composite Castings' (West Palm Beach, FL, US) high-performance thermoplastics replace metal in multiple parts, dropping high-performance engine's weight by 41 kg.
06/01/15 | short.compositesworld.com/TPBlock

AEROSPACE

All-composite helicopter program progressing toward type certification

Composite Helicopters International (Auckland, New Zealand) says it received 146 formal Expressions of Interest from potential customers during the 2015 HELI-EXPO event (March 2015, Orlando, FL, US) organized by the Helicopter Association International (HAI, Alexandria, VA US). The company called it "an extraordinary result" and a testament of support for its family of three helicopter models that feature its trademarked EvoStrength monocoque carbon/aramid fiber-reinforced composite airframe design (*CW* chronicled the company's debut in 2011 at the EAA Airventure show | **short.compositesworld.com/mE6NySrd**).


Source | Composite Helicopters

Composite Helicopters announced on Feb. 11 this year that it would proceed with type certification and has filed the Type Certification application with the New Zealand Civil Aviation Authority. Certification is anticipated for the KC630, equipped with a Rolls Royce 330-hp turbine engine, in late 2017, followed by the KC640 and KC650 models (equipped with larger turbines) in 2018. The company says a full design review is underway, led by chief engineer Nina Heatley, in line with the Federal Aviation Admin.'s *FAR* Part 27 certification requirements — a task that will run concurrently with the production of SN004, the latest composite helicopter to be fabricated and, when completed, will represent passage of a major milestone in the FAA type-certification process. It will include comprehensive peer reviews by industry experts external to the company, which will help ensure optimum performance of the aircraft and establish a benchmark for quality standards during pre-production.

Peter Maloney, company CEO, told HELI-EXPO attendees that the carbon/aramid construction provides a much stronger structure than conventional helicopter designs, and said the aircraft offers desirable high-altitude performance. Marketing head Lara Maloney says three additional helicopters will be built and dedicated to the certification testing program.

The design and engineering team are currently focused on manufacturing the next flight-test main rotor blades, in carbon fiber composites. Maloney adds that the company also is developing a framework for distributor and service center networks globally. See the HELI-EXPO video and hear Peter Maloney's remarks | **www.facebook.com/CompositeHelicopters**

CompoSIDE/Tsai cooperate in trace-based design demonstration

Web-based composites design firm CompoSIDE (Cowes, Isle of Wight, UK) has teamed with Stephen Tsai, professor research emeritus, Stanford University, to demonstrate further the benefits of Tsai's trace-based scaling approach to composites design (see endnote). Using CompoSIDE's functionalities, Tsai's team at Stanford and the CompoSIDE team say they have demonstrated that his innovative scaling approach to composites design can be applied to three-dimensional composite structures to develop designs within 2-3% accuracy margins, without the need for extensive and costly modeling and material testing. The next stage is to work with an industrial partner with a composites pilot project to benchmark the theory in the field. Tsai says, "The evaluation performed by CompoSIDE shows trace-based scaling models to have strong correlation with the FE results. We are seeking a highly loaded structure that has weight and cost challenges so we can confirm the potential of this new approach."

CompoSIDE joint managing director Julien Sellier adds, "Trace-based scaling removes many of the complexity and cost barriers to using composites."

According to Tsai's theory of universal stiffness and strength for trace-based composite laminates, trace-normalized stiffness components for all modern carbon-polymer composites laminates converge to nearly identical values. This universal stiffness means linear scaling, such as that found in a homogenous material, can be applied to the design. As a result, only a few simple tests are required to characterize composite materials. This approach reportedly simplifies composites design to the extent that it is similar to designing with aluminum and, therefore, provides designers and engineers a new framework for composites design, testing and manufacturing validation. It can thus deliver stronger, lighter, lower cost and more reliable composite structures with a simpler and faster methodology.

Read more abut CompoSIDE's Web-based composite design engineering solution | **short.compositesworld.com/CompoSIDE**

For background on Tsai's work and the significance of trace in the arena of laminate design, review the following at the *CW* Web site:

•"Overnight design allowables? An invariant-based method for accelerating aerospace certification testing" | **short.compositesworld.com/TsaiCerTst**

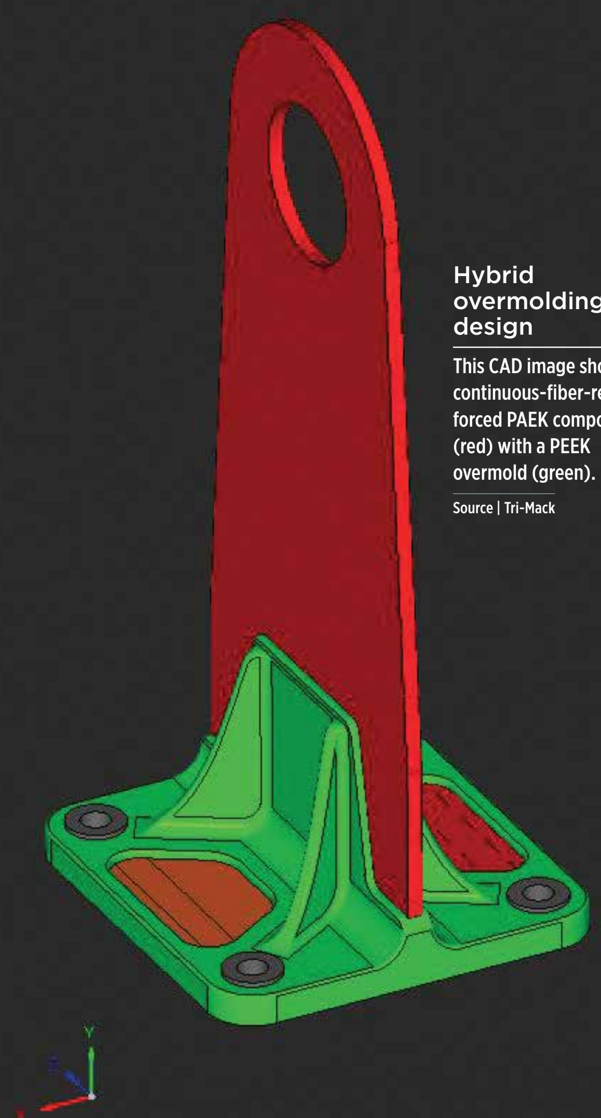
•"Tsai book expands on invariant-based method for material characterization" | **short.compositesworld.com/TraceBook**

•Tsai's paper on this subject, co-authored with Jose Daniel D. Melo, Alan Nettles, Waruna Seneviratne and Jared Nelson, is titled "Rapid and Accurate Design Allowable and Certification" and may be dowloaded at the CW web site in PDF format | **short.compositesworld.com/R**

Overmolding expands PEEK's range in composites

A new polymer and a hybrid process enable production of complex, high-load-capable, fiber-reinforced brackets and clips in minutes.

By Ginger Gardiner / Senior Editor



Hybrid overmolding design

This CAD image shows a continuous-fiber-reinforced PAEK composite (red) with a PEEK overmold (green).

Source | Tri-Mack

» In the composites industry, use of polyetheretherketone (PEEK) has recently experienced an uptick in thermostamped aircraft fuselage clips and brackets made from preconsolidated blanks with woven and/or unidirectional reinforcements (see "Learn More," p. 20). But those who use and those who make the blanks recognize their limitations.

"About 3-4 years ago, we recognized that compression-formed laminates did not offer the design flexibility and manufacturing efficiency being sought by aircraft designers," says Tim Herr, aerospace strategic business director for PEEK supplier Victrex Polymer Solutions (Cleveleys, Lancashire, UK). Drawing on the high-temperature-capable, high-performance resins' 25-year history in the aircraft industry in both filled and unfilled injection molded plastic parts, such as mounts and spacers, tubing, housings and electrical connectors, Herr's Victrex team and aerospace parts manufacturer Tri-Mack (Bristol, RI, US) began to explore the concept of injection *overmolding* as a means of overcoming the limitations inherent in thermostamping of preconsolidated blanks.

"The industry needed overmolding," he explains, like the organosheet process now common with polyamides and polypropylene in the automotive industry (see "Learn More"). Aerospace parts manufacturer Tri-Mack (Bristol, RI, US) already had begun exploring this type of PEEK processing as part of its thermoplastic composites development. The two have now demonstrated a new hybrid molding process for PEEK that uses a lower temperature continuously-reinforced Victrex polyaryletherketone (PAEK) composite as a substrate, overmolded with short fiber-reinforced PEEK, to produce a high-performance loaded bracket that is as much as 60% lighter than comparable metal components.

Hybrid composites-plastic processing

"Our idea was to combine the chemical resistance and moldability of thermoplastics with the high performance and light weight of composites," says Tri-Mack director of sales Tom Kneath. "Only then can thermoplastic composites penetrate into new applications where plastic alone cannot go because of the mechanical properties required." But the organosheet process is not without issues. Traditional steps include preheating a preconsolidated thermoplastic laminate to remelt temperature, transfer to an »

Best performance at least weight

Two views of a high-performance loaded bracket that demonstrates the new hybrid molding process, which uses a flat, lower temperature VICTREX PAEK composite substrate overmolded by short fiber-reinforced PEEK with co-molded metal inserts. The resulting finished bracket is as much as 60% lighter than comparable metal components. Source | Tri-Mack

open injection mold, closing the mold to thermoform the blank to shape and then injection overmolding with fiber-filled melt to provide the finished three-dimensional surface. As presented by Alan Wood at the 2nd International Conference and Exhibition on Thermoplastic Composites (ITHEC 2014, Oct. 27-28, Bremen, Germany), Victrex had to work through an array of issues, including support of the substrate during preheating, control of fiber orientation during forming, potential restriction to a uniform blank thickness to ensure matrix melting, and the development of polymers that would indeed fuse together during overmolding.

"We could mold PEEK over PEEK, but it doesn't fuse together," says Herr. Fusion of the matrices requires a substrate with a *lower* melt temperature than the overmold. "If you don't fuse the two, you don't consolidate the part," Herr points out. "So, we needed a low-temperature processing PAEK that has PEEK properties." Think of PAEK as the polymer family — Victrex can make different formulations, each with a specific molecular weight, melt temperature and T_g — with PEEK being one species. Thus, Victrex developed the PAEK A250 polymer, with a melt temperature of 305°C (see Table 1, p. 21). "We have enabled not only overmolding with PEEK," claims Herr, "but also the ability to achieve PEEK-type properties at processing temperatures similar to PPS or PEI with current equipment."

+ LEARN MORE

Read this article online | short.compositesworld.com/PEEKover

Read online about Daher-Socata's use of PEEK in thermoplastic composite fuselage clips in "Inside a thermoplastic composites hotbed" | short.compositesworld.com/TCHotbed

Read online about Premium Aerotec's automation of fuselage clip production in "Thermoplastic composites 'clip' time, labor on small but crucial parts" | short.compositesworld.com/RTPClips

Read online about injection overmolding in the auto industry in "CAMISMA's car back: Hybrid composite for high volume" | short.compositesworld.com/Camisma

Victrex also proved fiber orientation can be maintained during forming and that there is the potential for variations in substrate laminate thickness, which enables local tailoring of stiffness in the final part. The process requires less energy than anticipated, with substrate preheating typically maintained at 200°C.

Overmolding offers aerocomposites molders the advantages inherent in both molding "worlds": Complex aerospace *thermoset* composites can provide desired functionality and strength at low weight but "require hand layup and autoclave processing, resulting in parts production that takes hours to days," comments Kneath.

In contrast, injection molding of neat *thermoplastics* produces complex components in minutes, but limits the molder's ability to optimize part functionality. "What's great about this hybrid process," Kneath points out, "is that you can put the material *where you need it*, vs. standard injection molding, where you can't really selectively reinforce parts easily."

Because the substrate blanks are multi-ply composite layups, they are easily tailored for specific properties and/or load handling. For example, Tri-Mack has the ability to place and orient UD tapes in the blanks, using in-house automated molding cells. In fact, the company's Advanced Composites Center, adjacent to its main plant, was designed specifically to enable automated layup, consolidation and thermoforming of composite materials in conjunction with its legacy injection molding capabilities, to replace both metals and thermoset composites in aerospace applications.

Building a better bracket

To demonstrate the process, Tri-Mack needed a part that would deliver the message. "There are so many brackets used in aerospace," says Kneath, "and we've made a simple bracket with thermoplastic composites, so we decided to design a complex bracket shape that would also bear significant load." The design is loaded in three axes and incorporates four mounting points that rely on co-molded metal inserts in the PEEK overmold, the latter a typical feature of Tri-Mack's unreinforced thermoplastic brackets. "We load the aerospace-grade, carbon fiber-reinforced PAEK substrate and four metal inserts into a standard injection mold," describes Kneath. "We use a standard process to inject VICTREX PEEK 150CA30" — 30% carbon fiber-reinforced compound — "over the substrate, and minutes later, we have an integrated assembly that marries the performance of PEEK composites with the cost efficiency of injection molding." (See photo above.) Initial testing shows a very robust bond between the PAEK and PEEK matrices. "This will build confidence in the engineering community as they start to design parts exploiting this technology," Kneath asserts.

"The design flexibility is huge," he adds, noting the same bracket made with forged metal would require a significant amount of machining. "That's easy to beat with a 2-3 minute injection

Table 1

Victrex PAEK A250 vs. PEEK 150 Source | Victrex

	PAEK A250	PEEK 150P
Melting point (°C)	305	343
Glass transition temperature (°C)	147*	143*
Tensile strength (MPa)	90	100
Tensile modulus (GPa)	3.5	3.7
Tensile elongation (%)	15	15
Izod impact strength (kJ/m²)	5.0	4.5
** onset*		

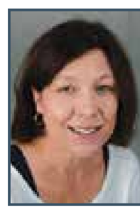
molding." Kneath concedes there is a tooling cost, but says the payback is usually pretty quick. "Most aerospace companies will say they don't have the volumes for injection molding, but we've been injection molding aerospace parts for 40 years, and know how to design tooling that balances cash and performance requirements."

Expanding PEEK's range

"We're getting a resounding response from airframers and others in the market," claims Herr. "This technology gives engineers the flexibility they want to design a very robust yet lightweight, load-carrying part." He explains this is one reason why Commercial Aircraft Corp. of China (COMAC, Shanghai) is fully engaged and actively looking at where PEEK can replace heavy, costly metals (see "Learn More").

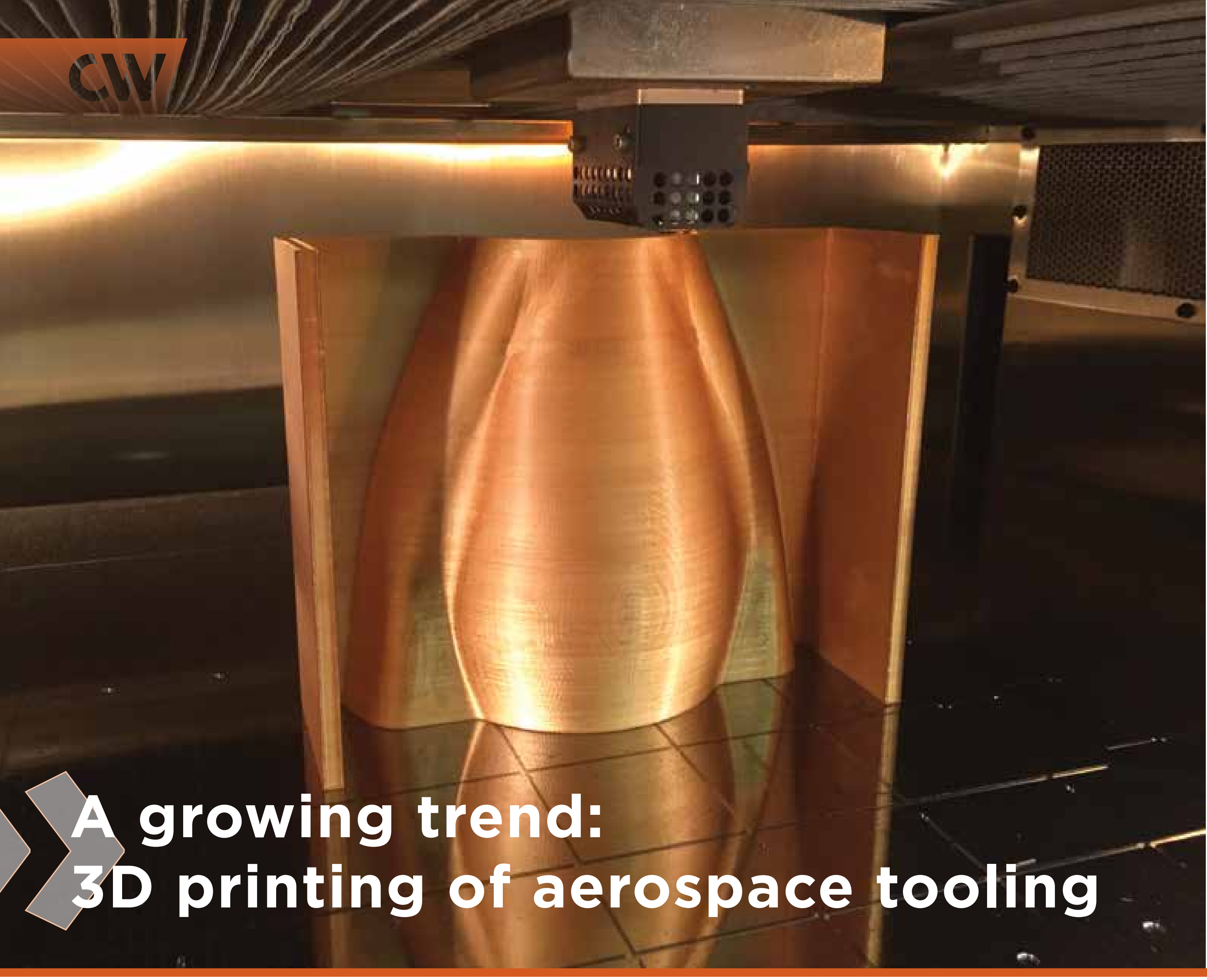
"This is an enabling technology, offering so many opportunities beyond brackets," says Kneath, adding that, given PEEK's mechanical and elevated-temperature performance and chemical/corrosion resistance, there are few areas where it's *not* a suitable solution. "We could be talking more complex housings or different types of panels with very thin, overmolded fiber-reinforced ribs." Tri-Mack also sees opportunities in the process for imparting multi-functionality. "We have evaluated technologies that would add lightning strike protection (LSP) paths or EMI shielding. This is typically done with secondary coatings or by adding a metallic layer to the layup," Kneath says, but Tri-Mack is now exploring how to do this via the compounds used in the hybrid processing.

"We see real opportunity to significantly expand PEEK applications in aerospace," says Herr. And, says Kneath, "We are also exploring applications for other industries as a next step." CW



ABOUT THE AUTHOR

CW senior editor Ginger Gardiner has an engineering/materials background and has more than 20 years of experience in the composites industry.
ginger@compositesworld.com



A growing trend: 3D printing of aerospace tooling

Toolmakers and OEMs are embracing additive manufacturing for customized, rapid tools, masters and jigs.

By **Sara Black** / Technical Editor

» Some pundits predict that 3D printing, or additive manufacturing (AM), will change our world forever. While that may yet be, one thing is clear: The growth of 3D printing over the past two decades has wrought significant change in composites *tooling*. *CW's* recent coverage of AM *parts* acknowledged 3D printing as a source of tooling as well (see "Learn More," p. 31), but the broad scope of the AM tooling trend justified the more thorough examination that follows.

Although AM's most obvious advantage is direct part production *without* tooling, the growing trend in the aerospace and automotive sectors at present is its use for fast, on-demand builds of mold tools to keep pace with accelerating composite part design cycles and demand for faster overall part processing speeds. "We've been looking at this for *years*, but now the technologies are getting better," one tooling expert recently confided to *CW*, citing the availability of faster, larger and less-expensive AM machines and higher-temperature materials that address some previous issues with rapid moldmaking.

"We're seeing some really good fits for additive manufacturing in composites tooling," confirms

Additive manufacturing of mold tools

A 3D-printed tool made with a new, high-temperature-capable polymer, Ultem 1010 from SABIC (Pittsfield, MA, US), is shown in the build chamber of a Stratasys (Eden Prairie, MN, US) printing machine. Ultem's properties make it useful as layup tooling.

Source | Stratasys

project engineer Dan Cottrell at Aurora Flight Sciences (Manassas, VA, US). But the key is that AM now enables its users to circumvent much of the lead time — much of it, simply *wait* time — and eliminate many of the multiple toolmaking steps that stand between the molder and the beginning of his first part production-and-assembly cycle. "Metal tools take *months*," Cottrell points out. "AM tools take days … or hours."

Challenges, and benefits

The focus here is on polymeric tooling (3D printing of *metal* tooling is a growing trend as well), and the sources interviewed for this article use fused deposition modeling (FDM) processes for 3D-printed tooling applications, at least at present. FDM is currently the most mature and widely used AM method. Given those parameters, the use of AM for aerospace tooling can be broken down into three broad areas:

1) Rapidly-produced master models, from which a part splash or reverse is made with more traditional composite materials.
2) Actual layup tools used to produce composite parts, either for autoclave or out-of-autoclave processes.
3) Washout mandrels for trapped tooling.

A fourth category — ancillary holding fixtures, jigs, trim tools, or metal forming dies — is expanding as well, and is the subject of "3D-printed fixtures and jigs," on p. 26.

AM for tooling still presents some challenges. For one, printer working size is limited, but sources agree that envelope restrictions do not limit tool size because a large tool or jig can be printed in segments and joined using thermal welding or structural adhesive bonding methods (that said, *large-format* AM technology is emerging; see "Learn More").

Another challenge: The use of 3D printing is what Mike Vander Wel, head of equipment and tool engineering for Boeing Commercial Airplanes (Seattle, WA, US), refers to as "application dependent." Low-temperature, short-run tools for prototyping that won't see high temperatures, for example, are commonly 3D-printed and well within AM's scope. But tools that must withstand the heat of a cure cycle in an autoclave? These, he says, are more formidable. "But our application envelope is expanding," he adds, because new materials could expand that space.

Heat is problematic, in part, because AM materials are (usually) unreinforced plastic polymers. They expand if heated, and it can be difficult to maintain dimensional stability as mold size increases, explains Tim Schniepp, a project manager and additive manufacturing research engineer with extensive aerospace experience at Stratasys (Eden Prairie, MN, US). "Coefficient of thermal expansion [CTE] is certainly a challenge, but there are ways to address or compensate for that," he says. Schniepp and Stratasys application engineer David Dahl recommend recently introduced Ultem 1010, a polyetherimide (PEI) polymer from SABIC (Pittsfield, MA, US) with a CTE about twice that of aluminum. Of all the materials available, to date, for FDM 3D printing, Ultem 1010 reportedly has the lowest CTE, and a T_g of 217°C. Another way for dealing with CTE is to avoid female tool designs, if possible, which can lock the part in the mold, and instead opt for mandrel, or male, approaches, where higher CTE can be used to advantage to provide consolidation pressure.

Challenges also include surface finish and tool porosity. "The way FDM works and lays down layers, yes, it creates some roughness on the surface, and there is going to be porosity," says Schniepp. Again, he and Dahl say it is not insurmountable. With some hand sanding — they point out that sanding is normally done in any case to finish tools made with composites — an acceptably smooth surface finish can be achieved. To deal with AM tool porosity, Schniepp recommends "envelope" vacuum »

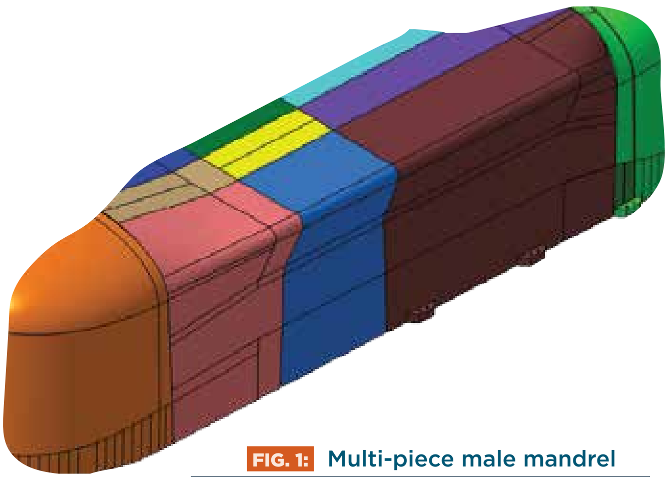


FIG. 1: Multi-piece male mandrel

This CAD drawing from Aurora Flight Sciences (Manassas, VA, US) shows a multi-piece printed male mandrel for an aircraft belly fairing, as assembled for layup of the part. A male tool design can help to mitigate issues with tool growth when heated. For a large part such as this, the use of multiple tool pieces mitigates the current limitations of 3D printers in terms of part size. Source | Aurora Flight Sciences

FIG. 2: Aircraft wingskin tools

The Boeing Co.'s (Chicago, IL, US) John Melillo reports that low-cost AM tooling reduced development cost for Boeing's *Phantom Eye* UAV. Many of its parts were made on 3D-printed tooling, including the huge wingskins for its 46m wingspan.

Source | The Boeing Co.

bagging, which completely encloses the part and the tool, negating the effects of potential porosity.

Schniepp also recommends the use of a good sealer, and Stratasys is working with Airtech International Inc. (Huntington Beach, CA, US), investigating ToolTec CS5, a Boeing-approved contact film material, and Toolwright-5 adhesive-backed film, both of which reportedly work well on relatively flat tools to eliminate porosity. The company also is looking at two-part liquid epoxy sealers, including Hysol EA-9394 from Henkel Corp. (Bay Point, CA, US) and BJB TC-1614 from BJB Enterprises Inc. (Tustin, CA, US), which are easier to apply on more complex tool shapes.

"In general," adds Schniepp, "the best sealer method is geometry-dependent, and our plan is to provide guidance in our upcoming design guide." The guide is a work in progress, led by Dahl, who with Schniepp works within the Vertical Solutions business unit at Stratasys, which provides actual application support for customers. (Stratasys also fulfills customer tool orders through its Stratasys Direct Manufacturing service bureau.)

SIDE STORY

Additive manufacturing in automotive applications

Although they have been overshadowed by aerospace applications, 3D-printed tools also are finding a place in automotive processing. One example is the composite technical center Plateau Technique Compositic (Ploemeur, France), affiliated with the Université de Bretagné-Sud, in Ploemeur. Compositic recently displayed a large, 3D-printed composite layup tool at the JEC Europe 2015 event in Paris.

Yves Grohens, a professor at the Université, says the tool was the result of research that combined additive manufacturing (AM) with robotic automated fiber placement (AFP) and other processing technologies, with the aim to create parts as rapidly as possible. "The concept is to compress the entire part design/tool production/robotic programming and part layup time. We are currently in discussions with several automotive OEMs about this innovative use of 3D printing."

Grohens explains that his group worked with automaker PSA Peugeot Citroën (Paris, France) on a model 208 demonstrator car roof part, in partnership with robotic system supplier Coriolis Composites Technologies (Queven, France) and SMM (Le Hezo, France), which manufactured the tool via AM. "The idea was to start from the virtual part in CAD, in the form of an .stl, .igs or other file format that is compatible with both a 3D printing machine and automated tape placement programming."

The tool's design and shape were developed from the part's CAD file and its print was begun by SMM, while Coriolis engineers simultaneously developed the optimum part layup and AFP machine path programming. The tool was printed on SMM's large Fortus 900 FDM machine, supplied by AM equipment manufacturer Stratasys (Eden Prairie, MN, US), with approximately 1m^3 of useful build volume. Total build time was about 100 hours.

Stratasys provided polycarbonate powder for the print build, without fiber reinforcement, but Grohens says, "We achieved sufficient stiffness and thermal stability with the polycarbonate for this demonstration tool but, in reality, it would be made with polyetherimide [PEI] Ultem material in production, to enable a higher cure temperature of 180°C and higher pressure. We limited the actual cure temperature of this demo tool to 140°C."

Tool weight, when complete, was 14 kg. No mold treatment of any kind was undertaken after the print, says Grohens.

Immediately after the mold was completed, it was placed under the Coriolis robotic head to begin the part layup, using 6.5 mm wide carbon/epoxy prepreg tapes. Grohens says that the part layup process, which was completed in a day, was successful the first time, because tool build, part design and robotic processing were developed simultaneously, within the same digital space. He adds, "If we had proceeded with classical mold machining and a metallic tool, requiring test articles to ensure correct layup, this process would have taken at least two months to reach that perfect state."

Although the untreated mold caused no problem for the part layup and cure, he does add, "The tool surface is a little bit rough, so on subsequent tools, we treat the surface with an epoxy coating that reduces the roughness and provides a better part surface finish."

Compositic is pursuing similar projects with partners, including Airbus, for 3D-printed tool applications.

Developmental tooling

This polycarbonate layup tool, used to produce a carbon fiber composite auto roof, was additively manufactured by SMM (Le Hezo, France) using the machine behind the tool in the top photo, in partnership with a French group that included Plateau Technique Compositic (Ploemeur, France) and Coriolis Composites Technologies (Queven, France). The tool is shown in the bottom photo during layup with a Coriolis robotic tape layup head.

Source (both photos) | Plateau Technique Compositic

Says Dahl, "There is so much demand now, and so much interest in this technology for tooling, we believed the design guide was warranted." Scheduled for release in early 2016, it will give concrete advice to customers using AM for tooling production.

Aurora Flight Sciences, for one, is an active and enthusiastic customer/partner with the Vertical Solutions group, because, Cottrell says, "we've got a lot of actual experience, now, making parts on these tools."

A viable alternative to traditional tools

Limitations and challenges notwithstanding, AM tooling is earning a place in the aerospace composites toolbox. Cottrell has worked with Stratasys on the design and build of 24 tools, so far, for parts flying on low-volume UAVs as well as for commercial aircraft customers. One example, currently in process, is a 2.8m long by 0.6m wide by 0.6m deep tool, made with polycarbonate, for a belly pod fairing. Rather than produce a female tool, relates Cottrell, the Aurora Flight Sciences/Stratasys team designed a male mandrel, divided into multiple segments (see Fig. 1, p. 23). When the segments are joined, and it and the pod layup are bagged against a large plate, the arrangement will allow the plies to move and grow slightly with the tool against the vacuum bag during cure — the male tool geometry will provide some compaction, without the worry that the laminate will restrict tool growth, or that the tool will break fibers. "We had worked with Stratasys to test some printed coupons made from layups on both male and female geometries. The coupons from the male layups produced well-consolidated laminates," he explains. "We're not very strict on the finish of the outer mold line [OML] for this part, so the male mandrel approach will work well."

"AM tool structure can be optimized to any degree you want, because the print file can be easily modified," asserts Dahl. An optimized tool, he explains, can be made thicker in some areas, and thinner in others, and the internal support build structure can be modified by varying the print raster paths and internal support density. These techniques provide strength and rigidity where needed, and can minimize tool expansion and movement, depending on the part processing methods. (Dahl also worked with Cottrell on a series of AM *trim* tools for another project, described in "3D-printed fixtures & jigs," p. 26)

Most telling is how tooling lead time can be compressed. Cottrell explains that a typical aluminum or composite production tool takes about two months to design, produce, finish and ship, contrasted with the seven days required for an AM tool of similar size. The tool cost per cubic centimeter is less than half that of a metal or traditional composite version, minus the cost of the printing machine. "And this is for a *solid* tool," Cottrell points out. "We could make it for even less, using less polymer material, if it were better-optimized."

Aurora Flight Sciences is involved in several proprietary programs with major OEMs that involve printed tools. "One of the beauties of this technology," says Cottrell, "is we can test, iterate the design, incorporate lessons learned into the final tool design and still have it done within days." »

FIG. 3: Tooling for washout mandrels

Nevada Composites (Dayton, NV, US), a producer of washout tooling mandrels, uses FDM printed tooling to mold its water-soluble products.

Source | Nevada Composites

FIG. 4: Washout mandrels for pressure vessels

ExOne (North Huntingdon, PA, US) says this test mandrel (middle photo) for this pressure vessel was 3D-printed using fine foundry sand mixed with a water-soluble binder. This binder remains water soluble at temperatures up to 190°C, and higher-temperature silicate binder is an option. Source (both photos) | ExOne

SIDE STORY

3D-printed fixtures & jigs

Holding fixtures, jigs, trim tools and metal-forming dies can be expensive elements of post-mold composite part processing and assembly. Designing and building such tools can be an expensive and time-consuming part of the production process in its own right. Additive manufacturing, therefore, is proving especially useful in this area.

One application is in the post-mold trimming of similar but not identical series-molded parts. Aurora Flight Sciences (Manassas, VA, US), for example, recently produced a series of female bulkhead tools, 3D-printed in polycarbonate, for a UAV demonstrator.

"We've pulled about six parts from the bulkhead tools so far," says project engineer Dan Cottrell. David Dahl, an application engineer for AM supplier Stratasys (Eden Prairie, MN, US), explains that AM enabled successful production of the bulkhead parts: "Traditional metal tools typically are designed with scribe lines machined into the surface that transfer to the composite parts, and guide post-cure trimming operations. But you can't really print a scribe line on an AM tool." Because each bulkhead is shaped slightly differently, parts made on the same tool end up with different dimensions because they're trimmed uniquely. Cottrell says that to save time during trimming and finishing, Stratasys simply printed lightweight trim tools (router templates) for each bulkhead version, in a matter of a few days, to expedite the trimming process (see photo at left). "We were able to generate an entire tooling family, very economically," he adds.

Trim Tools

When Aurora Flight Sciences (Manassas, VA, US) produced a series of female bulkhead tools, Stratasys (Eden Prairie, MN, US) simply printed lightweight trim tools (router templates) like this one for each bulkhead version, in a matter of a days, to expedite the trimming process.

Mike Vander Wel, head of equipment and tool engineering for Boeing Commercial Airplanes (Seattle, WA, US), describes another application: the use of AM to build a drill jig for an older aircraft part. Because legacy aircraft — US Air Force tankers, for example — were built before digital engineering tools were available, it can be time consuming to develop a mold, or holding fixture, for a replacement part.

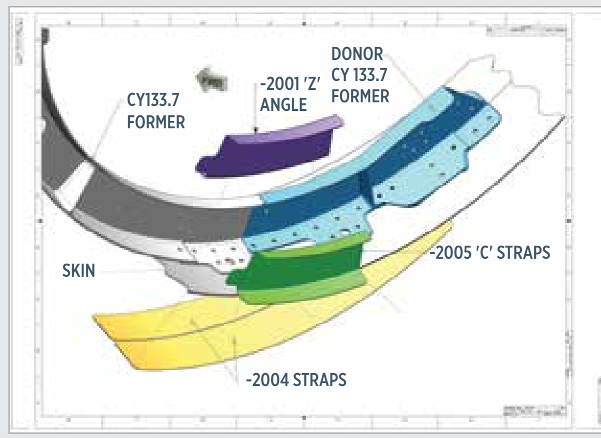
"If we had made this drill jig in metal, it would have cost at least $50,000," he says. Instead, the part that required replacement was laser scanned, which captured the part dimensions in a CAD file that could be easily transferred to the 3D printer. A holding jig was then 3D-printed using a low-cost plastic polymer within a few days. The jig enabled support and fast drilling of the metal replacement part. "This is a great example of how we can justify the cost of placing and using 3D printers in our facilities in a matter of months," adds Vander Wel.

Robert "Yogi" Kestler, Science & Technology (S&T) lead; Robert Thompson, a materials engineer; and Douglas Greenwood, an aerospace engineer, at FRC East (Cherry Point, NC, US), the maintenance, repair and overhaul center for all US Navy and Marine Corps vertical-lift aircraft, tell of a set of 3D-printed fixtures used to repair a damaged AV-8B *Harrier* jet, which lost its front landing gear during a flight from the aircraft carrier *USS Bataan*. To safely land, the pilot had to descend vertically and place the aircraft's nose cone onto a padded cradle, which substituted for the inoperative gear. All went well until the last moment, when the plane bounced, damaging an internal metal frame within the nose. After damage assessment, repair planning and structural analysis, Kestler's group received the CAD solid model of the frame on a Wednesday, began 3D printing the next day, and on Friday, tooling blocks were complete.

Greenwood explains that the AM blocks, made in polycarbonate on FRC East's Stratasys Fortus 400mc and 900mc AM machines, enabled forming of stainless steel Z- and L-shaped metal doublers that were subsequently mechanically fastened, on board the ship, to splice a new portion of the frame that replaced the damaged portion of the frame (see images above). "The combination of the CAD solid model geometry and software, our tool designers, our AM machines and a dedicated workforce enabled a one-week total turnaround of the parts needed for this repair, which is pretty remarkable." A link to a YouTube video of the *Harrier* jet's hard landing is provided in "Learn More," on p. 31.

Forming Fixtures

These polycarbonate tooling blocks, produced on a Stratasys (Eden Prairie, MN, US) FDM machine, were printed in one day and used to form stainless steel repair doublers to repair a damaged frame within the nose cone of an AV-8B *Harrier* jet fighter. Source | NAVAIR



Doublers for nose repair

This CAD drawing shows how the shaped metal doublers were fastened for the AV-8B *Harrier* nose cone frame repair. Source | NAVAIR

OEMS at the forefront

Boeing and Airbus are following this trend, closely. Boeing was an early adopter, and began 3D printing as early as the 1980s, says Mike Vander Wel, head of equipment and tool engineering for Boeing Commercial Airplanes: "We were pushing the envelope back then. In the past few years we've been looking harder at this, and integrating it into our operations more systematically." Vander Wel notes that it has been an "evolutionary, not a revolutionary" journey, and says, "It is absolutely viable as a technology, for both parts and tools." He cites three factors for Boeing's increasing adoption of the technology: the cost of printing itself has dropped, material cost has also decreased and the degree of innovation is changing radically, resulting in continuous improvements.

Vander Wel points out that AM'd tooling enables the company to accelerate design cycles: "In the past, it was long lead times to get parts and tooling to the factory floor, but with this technology we can turn around design concepts much faster." The cultural change has been encouraged by the fact that Boeing has made industrial 3D printing machines — mostly Stratasys Fortus 400 and 900 systems — directly available to engineers right at its manufacturing sites, to encourage experimentation and use. Further, Boeing has partnered, since 2005, with the Lotus Formula 1 auto racing team to test and incorporate 3D printing technologies into its extremely fast vehicle development cycles — cycles that the aircraft OEM can't match. That partnership led to a Boeing patent on the use of chopped and milled recycled carbon fiber (from its composites fabrication waste) to create stronger printed parts, reportedly with isotropic distribution of short fibers (see "Learn More").

> The Boeing *Phantom Eye* UAV's huge 46m prepreg wingskins were layed up on 3D-printed tooling.

Vander Well credits AM tools with helping to keep costs low and schedules in line for the company's high-altitude, long-endurance (HALE) *Phantom Eye* and newer *Phantom Swift* vertical-takeoff-and-landing (VTOL) prototype UAVs (see "Learn More") developed by Boeing Phantom Works (St. Louis, MO, US).

Nick Melillo, of Boeing R&D, spoke in 2013 at the SAMPE Europe conference in Paris about the use of low-cost AM tooling and how it reduced *Phantom Eye* development cost, without adversely affecting the vehicle's design. The prototype *Phantom Eye* has a 46m wingspan, and its huge wingskins were made with out-of-autoclave-capable prepregs layed up on AM tooling (see Fig. 2, p. 23), as were many other of the aircraft's structural parts.

Melillo was unreserved in his praise, "3D printing for tooling and parts is going gangbusters." »

The right tools for aircraft repair

AM is significantly useful in aircraft repair and maintenance. Cottrell notes that AM technology has become invaluable for repair of legacy aircraft for which OEM spares are no longer available. The U.S. Department of Defense (DoD), for example, operates several repair depots around the US, and elsewhere in the world, to keep aging defense aircraft flying. The Fleet Readiness Centers (FRC) of the US Naval Air Systems Command (NAVAIR) use AM tooling to mint spare parts that are otherwise hard to come by or are simply no longer available, says Robert "Yogi" Kestler, Science & Technology (S&T) lead at FRC East located at Cherry Point, NC, US. FRC East is the maintenance, repair and overhaul center for all US Navy and Marine Corps vertical-lift aircraft. "Composites are a big part of what we do, day to day, and it's growing as older, metal-centric aircraft are retired," adds Robert Thompson, a materials engineer at Cherry Point.

> AM tooling is proving to be a cost-effective resource for molding replacement parts on aging DoD aircraft.

Douglas Greenwood, an aerospace engineer at the center, says that a typical legacy composite repair project used to require manual methods to capture part geometry, replicating those part features with a low-temperature fiberglass splash, then making a reverse mold followed by a production tool for part layup. But, AM and digital tools are transforming that process. Today, a 3D scan captures part surfaces, either with a contact device like a FARO Arm (FARO, Lake Mary, FL, US) or noncontact laser scanning, and the scanned data are converted into a solid CAD model. From there, the data can be fed to a 3D printer to quickly make the tooling for a replacement part.

Greenwood and Thompson say the group obtained its first 3D printer in 2006, and began to investigate making parts for "fit and form" applications, that is, validating CAD file information to ensure a part would fit properly, before undertaking conventional CNC machining and/or mold production. Later, in 2010, the group began more serious experiments, including direct 3D-printed tooling. Across the three industrial FRC installations, NAVAIR operates nine 3D printers, employing FDM and three other types: jetted binder, stereolithography (SLA) and selective laser sintering (SLS) technologies. Says Kestler, "Our AM efforts for composite tooling are still in their infancy, right now, but we're very interested in moving forward."

Greenwood echoes previously noted concerns about managing CTE issues and finding AM materials able to withstand autoclave conditions. Given that, FRC East currently prefers the approach of using AM to print a master pattern with FDM polycarbonate, then using it to make a carbon/epoxy mold. But the group also is working with industry on composite tools, using filled photopolymer resins that could withstand high-temperature, high-pressure conditions.

Printing trapped tooling

Trapped tooling is another AM option. Sometimes called "lost-core" tooling, it refers to a shape or mandrel, around which a part is molded, that is subsequently removed after part cure. Removable mandrels have been in use since the beginning of composites manufacturing. Trapped tooling materials vary widely. They can be made from inflatable bladders, complex extractable (collapsible) metal mandrels, breakable cores of eutectic salts, ceramic, foam, plaster or urethane, and so-called "washout" tooling, made of soluble material that can be dissolved or melted and removed. At least three suppliers are using AM to rapidly print, rather than laboriously mold, water-soluble trapped mandrels to fit any complex shape. Stratasys is one.

Advanced Ceramics Manufacturing (ACG, Tucson, AZ, US) offers RapidCore, a 3D printed material that reportedly withstands autoclave pressure and temperature (see "Learn More"). It has been adopted by Boeing, Airbus and other OEMs. Although Nevada Composites (Dayton, NV, US) is not using AM to *directly* produce its Green-Aero washout mandrels, it is printing ABS with FDM methods to produce the complex tools within which its washout mandrel material is molded (see Fig. 3, p. 25).

Founded in 2005, ExOne (North Huntingdon, PA, US) provides both 3D printing machines and 3D printed products. ExOne has worked for years printing sand particles to make casting molds and cores for metal parts, but now offers 3D-printed water-washout tooling for composites manufacturing. Jessie Blacker, ExOne's product development manager, says, "Our printed cores can be produced quickly and then simply washed out of a part after cure." For low-volume manufacturing or proofing, ExOne can print tool bodies that, after coating, can last for short runs of parts under most processing conditions.

Blacker describes a test mandrel printed in a pressure vessel shape, using fine foundry sand mixed with a water-soluble binder. The binder system remains water soluble at temperatures up to 190°C, sufficient for most composites processes. "We offer a silicate binder if temperatures need to go higher," he says. He also explains that mandrel CTE can be modified to customer specs by varying the base sand material — for example, metal powders, carbon, zircon or ceramic can be added — to achieve a CTE almost equal to that of carbon fiber, to match tool and part »

> 3D printing of soluble tooling materials eliminates the step of having to make a mold for the trapped tooling.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(see Fig. 4, p. 25). The test mandrel was coated with a solution based on the same binder system, but at a higher concentration, then hand-sanded and sprayed with a PVA mold release. The mandrel then was filament-wound with a carbon fiber towpreg overwrap and oven cured at 135°C for two hours.

After cure, it was not only possible to wash away the mandrel with water but also to completely recover all the sand after the binder dissolved, reports Blacker, which then can be reused: "The material is compatible with all resin systems — with the exception of phenolics, which give off moisture during cure — and can withstand autoclave pressures."

In addition to washout tooling, ExOne also prints prototype, master pattern and standalone layup tools, in a variety of sand and fine-grained metal materials with tailorable CTE, to match process needs. "For layup tools or master patterns, we would recommend using one of our nonsoluble binders," adds Blacker.

The only direction is up

Boeing's Vander Wel stresses that young engineers recognize that toolmaking is no longer limited to subtractive methods, and that wider adoption of AM is on the horizon: "This technology is barely in its infancy today. We will have lower-cost and higher-strength materials, with embedded fibers, and larger build sizes — there are some really exciting possibilities coming for AM."

Schniepp of Stratasys concludes, "There are real, long-term benefits to this technology for tooling. We're passionate about AM and its potential for changing the way that things are made." CW

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ABOUT THE AUTHOR

Sara Black is *CW's* technical editor and has served on the *CW* staff for 17 years.
sara@compositesworld.com

Bespoke sports cars' composite body speaks volumes

Supercar looks/commuter car economy

This composite-bodied, two-seater touring vehicle, built by Trident Sports Cars Ltd., a startup automaker in the Norfolk area of England, offers several models with performance approaching that of supercars but the fuel economy of hybrid-electric vehicles or diesel-powered micro-city cars. Key to this performance is the company's core product: its patented torque-multiplication technology (see the Side Story on p. 36). Source | Trident Sports Cars Ltd.

Glass-reinforced plastic artfully captures classic curves, crash-protects passengers and stunningly packages its maker's high-performance but highly fuel-efficient *diesel* powertrain.

By Peggy Malnati / Contributing Writer

» His customers, said Henry Ford, Sr., could buy a car in any color, as long as it was black. Attributed to the founder of Ford Motor Co. (Dearborn, MI, US), this famous quote signaled the end of an era in which nearly everything, even the automobile, was handmade, and thus, could be custom made to order. Ford understood that the secret of mass-producing goods at low cost was to make them all the same, or to greatly reduce choice. Today, when nearly everything purchased in the developed world is mass-produced, there is a powerful longing for that which is personally custom-crafted. Sensing that "old school" undercurrent, startup automaker Trident Sports Cars Ltd. (Swaffham, Norfolk, UK) is using fiber-reinforced plastic (FRP) and a skilled workforce to create bespoke luxury sports cars that showcase a unique transmission technology and multi-fuel engines that can satisfy the very modern imperative to render vehicles carbon neutral in operation.

Marketing massive torque

Trident's Phil Bevan and partner Dan Monaghan have spent much of their careers working in automotive R&D. But when they opened the doors at Trident in 2005, it wasn't to develop cars *per se*, but instead to commercialize their proprietary *torque-multiplication* technology, the result of a project into which they had sunk £6 million (US$9.3 million) of their own money. The vision? Build a business that would manufacture *many* products — cars, yes, but also commercial trucks, military vehicles, powerboats and even wind turbines — that could incorporate and benefit from that unique technology.

What is *torque-multiplication technology*? As the name implies, it is a combination of hardware and software algorithms that multiply the torque produced, for example, by an internal combustion engine of a given horsepower rating, enabling it to deliver expected performance at much lower-than-typical engine

Convertible or fastback

There currently are two basic *Iceni* models available: the convertible (top) with a unique central spine/roll bar for protection, and the fastback-style *Magna* (bottom) with a full roll cage. But both can be ordered plain or dressed out from four upgrade packages, three engine options, and nearly any interior and exterior color combination. Source (both photos) | Trident Sports Cars Ltd.

RPMs, and thus, with greatly reduced fuel consumption; alternatively, it offers extraordinary performance at ordinary RPMs/fuel consumption (for more, see "Torque-multiplication: A Euro 7-ready *diesel* supercar?"). Trident's potential military vehicle customers, then, would find that, compared to a *Humvee* or High Mobility Multipurpose Wheeled Vehicle (HMMWV) armored troop carrier from AM General (South Bend, IN, US), which burns fuel at a rate of 34L/100 km on a good day, a Trident military vehicle would deliver fuel ratings of 6-8L/100 km — a *big* savings for armies or rescue organizations that must carry all their fuel as they move.

Although their ambition is to be far more than a car company, the partners felt it would be most expedient to showcase their technology on a high-end, two-seat sports car. Thus on display, the Trident powerplant — a modified V8 Duramax diesel engine from General Motors Co. (GM, Detroit, MI, US) — using the »

SIDE STORY

Chassis: Unique architecture and materials

Trident Sports Cars Ltd.'s *Iceni* chassis is formed from 4003 low-chrome/low-carbon stainless steel, supplied by Columbus Stainless (Pty.) Ltd. (Middelburg, South Africa). It isn't pretty (see photo), says Trident's Phil Bevan, but it won't rust (the frame is warranted for a century), and more importantly, it's very resilient (won't workharden), making it perfect, he says, for chassis construction. That means the

Stainless-steel, origami-style chassis

Trident elected not to use the tubular steel "space frame" concept common in high-end performance car design and went, instead, for a chassis cut from sheet stainless steel, then *folded* via an industrial-origami technique and welded into shape.

Source | Trident Sports Cars Ltd.

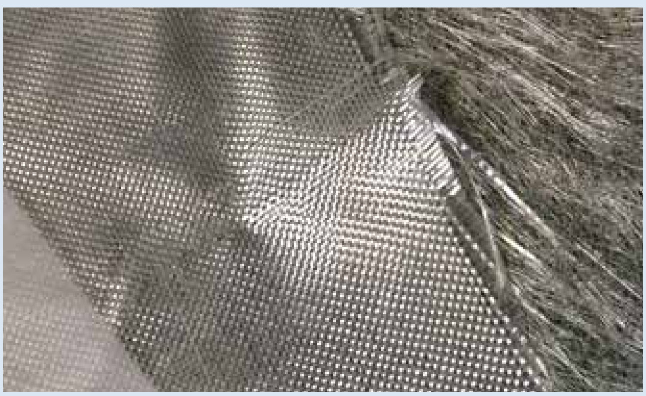
Iceni has the highest torsional rigidity of any sports car not using a carbon fiber composite chassis, which, in turn, reportedly means that in a head-on crash at 161 kmh, the engine won't land in the driver's lap. Because it won't workharden, damaged stainless steel can be reworked nearly endlessly without losing its properties and becoming brittle, yet it's fully recyclable.

The *Iceni's* chassis is not, however, a conventional tubular frame. Chassis components are laser cut from sheet metal, then folded via an industrial-origami technique and then TIG (tungsten inert gas) welded. This "disruptive" technology enables startup or established automakers to enter new segments with a much smaller upfront investment, making it ideal for low-volume vehicles. Bevan says the *Iceni* is the same size as the Aston Martin *DB9* luxury sedan with an aluminum chassis (from Aston Martin Lagonda Ltd., Gaydon, UK), yet is one-third stronger, 24 kg lighter and reportedly far more easily repaired.

The *Iceni* convertible's chassis includes a central, longitudinal spine/rollover bar, and strategically positioned folds and shapes (further benefits of an origami vs. tubular frame) that enable the vehicle to form a strong passenger cell. This cage not only provides excellent occupant crash protection, but also is designed to prevent anything from penetrating the bulkhead. The mid-front-mounted engine is designed to drop down and become wedged in the tunnel during a crash, and even the crankshaft pulley stays around the car's wheelbase.

The vehicle also sports 8-cm-wide seatbelts with strong anchorage points. Reportedly, when the car was tested, it had the strongest chassis ever assessed for seatbelt retention.

1 Single-sided composite tooling receives a coating of wax prior to start of layup.



2 Depending on mechanical requirements in each area of a given part, either a chopped fiberglass mat (right) and/or a woven fiberglass fabric (left) is used.

3 The reinforcement is hand cut, using paper templates, then layed up into the tool.

4 When each layer of reinforcement is in place, unsaturated polyester resin is carefully hand applied in a laminating step. The goal is to avoid adding too much resin, which otherwise could cause cracking. During this step, flanges and other hardware are also bonded into parts.

company's torque-multiplication technology and either of Trident's own six-speed automatic or manual transmissions, would use a mere 4L/100 km. If well executed, they reasoned, this first example would ease technology translation to commercial and military vehicles. Hence, they assembled a team of 30 to build very green sports cars and commercial vehicles. Along the way, they acquired and subsequently modified the name and logo of another automotive icon — a British car company from the 1960s and 1970s called Trident Cars Ltd. — and set up shop in the Norfolk area, also home to another automotive icon, Group Lotus PLC.

Unlike its neighbor, which turns out around 7,000 cars a year, Trident's goal was to build as many as 500 truly bespoke cars annually that would be as easy on the environment as they were on the eyes. In a consciously ironic nod to certain Italian manufacturers of premium sports cars, their first nameplate, *Iceni,* bears the name of a Norfolk-based Celtic tribe that, for a time under the leadership of Queen Boadicea, led an uprising that routed the Roman invaders and drove them out of southeast Romano Britain. Time will tell if the name proves prophetic.

Options, options, *options!*

Although the *Iceni* is intended as a testament to Trident's technical capabilities and developmental achievements in the powertrain arena, it is no less important to the company that it have enormous appeal as an automotive achievement. Currently, Trident offers two basic *Iceni* models: A convertible that features a unique spine/rollbar that extends rearward from its windshield to its seatbacks, and the *Magna*, which has a fastback coupé design that features a full roll cage (see photos on p. 33).

5 Parts are cured in a paint-spray booth (without vacuum) for 4 hours at 70°C. After demolding and degreasing, a polyester spray filler is used to smooth out imperfections, then inner and outer panels are bonded, using a methacrylate adhesive.

6 Next, parts are primed with a two-part system, and the part's B-surface is painted.

7 After finishing, panels are adhesively bonded to the chassis in 24 locations, using top-hat sections. Finally, panel A-surfaces are painted.

Source (all step photos) | Trident Sports Cars Ltd.

That said, Trident's manufacturing philosophy is the antithesis of Henry Ford's one-color-fits-all philosophy. *Icenis* are available in *any* paint color and nearly any color leather interior — even the contrast stitching option on interior trim and seating uses two twisted strands to produce double-color accent stitching (that will be trademarked). Furthermore, the twin double-bubble shaped "Occulite" polycarbonate roof panels are available in six colors. They enhance visibility, extend headspace, protect occupants in a rollover, and store in the boot/trunk when not in use. (The car can be driven with one or both removed and, reportedly, the aero-dynamics are so good, occupant hairdos remain undisturbed!) Further, each model can be had plain or dressed up with one of three engine options, front and rear wing vents, side exhausts, and/or twin plenums protruding through the hood (paired with a twin-turbo-charged engine upgrade).

Each vehicle can be further customized through four upgrade packages: track performance; premium-, performance-, and luxury-upgrade packages. And that's only the beginning. In fact, *Icenis* feature more than 39 bespoke components — 67% of the car — that are designed and built by the Trident team, including chassis, body panels, wheels, seats, instruments, engine electronic-control module (ECU), gearbox, differential, transaxle, roof panels, head/taillights, and grilles for what the company describes as a "truly unique performance-motoring experience." Each chassis, for example, is formed from a low-chrome/low-carbon stainless steel that is easily repaired, recyclable and guaranteed for *100 years* (see the Side Story on p. 33). Bevan says every car is built to meet customer needs. Sales are done direct, not through dealers. "We're in touch with our customers from beginning to end. It's nearly impossible for us to make two *Icenis* exactly the same." »

SIDE STORY

Torque-multiplication: A Euro 7-ready diesel supercar?

At Trident Sports Cars Ltd., the signature feature of the *Iceni* sports car drivetrain is the team's unique torque-multiplication technology, for which the company holds 64 patents. When it's harnessed with a modified 6.6L turbo-charged direct-injected V8 Duramax diesel engine from General Motors Co. (GM, Detroit, MI, US), and Trident's own six-speed automatic or manual transmissions, the *Iceni* models powered by the combination are fully compliant with Euro 6 diesel emissions legislation that phases in this year. In fact, Trident's powerplant surpassed Euro 6 requirements in 2008, and in 2012 it surpassed Euro 7 emissions mandates, which won't become law until 2020.

Duramax engines typically power GM full-size pickups and commercial vans — vehicles known for power/torque, not speed. Nevertheless, the above combination enables the base *Iceni* to accelerate 0-97 kmh in 3.7 seconds and top out at 306 kmh, putting it in supercar territory. The base vehicle produces 397 hp and 700 lb/ft of torque, but engine upgrades can boost that to 430 and 660 hp, producing 950 and 1,050 lb/ft — more than *three times* the torque of a typical high-end sports car or supercar — and accelerating 0-97 kmh in 3.2 and 2.9 seconds, respectively.

"Just as everyone thinks there's no substitute for cubic inches in the engine," explains Trident's Phil Bevan, "they also obsess over crankshaft horsepower. What they fail to realize is that if you're running a car at 8,000-9,000 rpm, you're going through fuel at a rapid clip. We've taken a different approach and change gears at 3,000 rpm. By cutting engine revs by more than 50%, we also halve fuel use and emissions. People overlook the value of torque." But Bevan observes that the low horsepower/high torque that defines Trident vehicles can be both blessing and curse because it yields a ... *different* driving experience. No potential customer of a Trident *Iceni* can buy a car without a test drive or two.

Another unique aspect of all Trident's vehicles is that they feature multi-fuel engines that will run on *any* oil-based fuel, from conventional diesels or bio-diesel to mineral oil, paraffin, kerosene and central-heating oil. When fueled by annually renewable, carbon-fixing, plant-based bio-diesel (e.g., from new or used cooking oil), the vehicles offer another unique benefit: Plants from which cooking oils are derived absorb carbon and nitrogen (greenhouse gases) during their growing cycle. When they are harvested, and ultimately used to make a bio-fuel, they represent a credit — a net carbon offset. When bio-diesel is burned in the Trident vehicle, the owner, in theory, cashes in on the carbon credit from the plant's work during its lifecycle, especially if the fuel is made from *used* cooking oil. Then the vehicle technically operates at a zero (net) carbon footprint.

Onboard diagnostics and computer-controlled systems will sense fuel changes from tank to tank and automatically adjust various combustion conditions and other ratios to maximize efficiency. To reduce emissions further, a new feature, *hydrogen injection*, will kick in and burn any unburned fuel and particulates when the engine isn't operating at maximum efficiency.

In the lap of luxury

Trident's bespoke philosophy extends even to the decorative stitching on the *Iceni's* interior leather trim, which features two twisted strands of thread (above) for a super-customized look. Source | Trident Sports Cars Ltd.

Perfecting the package

Then there's the no-less-impressive body design. Bevan says a lot of classic cars provided styling cues for the *Iceni*: "We borrowed the nose cone off a *Ferrari* and the back windows off a '63 [*Corvette*] *Stingray* and this and that. When you put it all together, you have a whole new car."

With a car this fast, this curvy and produced at such low volume, selecting composites for the body panels was a "no-brainer." The tooling for steel body panels would have been too costly, and aluminum panels couldn't deliver the vehicle's plethora of compound surfaces. The *Iceni* is lusciously curvaceous, and many of those curves play an important safety role. Bevan says they worked from the outside in to shape the car and add as much curve as possible. "Nothing's straight," he points out. "We don't want any stressed members. The body doesn't have to do »

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anything except make the car safe." To that end, all models are equipped with crushable composite nose cones. Even the vehicle's twin-baffle, 50-mm composite "pontoon outriggers," flared sections near the bottom of door sills, provide protection from side impacts. Because everything bolts to the chassis, rather than to the body, the latter is completely unstressed.

However, when Bevan and his Trident teammates initially looked at carbon fiber prepreg, he says they were disappointed with trial panels, especially for the doors. "Everything *sounded* awful," he explains. "The panels were too light for us. We wanted a Grand Tourer vehicle, an *expensive* product, so we had to get the sound right."

Because they already had a fairly lightweight chassis, the mass of body panels was less critical. "Torque is the great equalizer to lightweight construction," Bevan contends, noting that the solution was, therefore, counterintuitive: The team hand lays *glass* fiber composites with an unsaturated polyester matrix (Crystic 2.446 PALV from Scott Bader Co. Ltd., Wellingborough, Northamptonshire, UK), with a chopped fiberglass core mat (CS mat 92, 300 and 600 g/m^2, from Zibo PPG Sinoma Jinjing Fiber Glass Co. Ltd., Zibo, China). "We actually make our panels *heavier* than is strictly necessary, but when you tap on our body, it sounds like cast iron, not tin. *That's* the kind of sound we were after."

Where extra strength is required, woven mat from the same supplier is used. At the front of the nose cone, for example, near the front grillwork, the layup is straightforward 136 g/m^2 chopped strand mat construction, says Bevan. But as the layup progresses rearward toward the bonnet/hood shut line, where the nose cone joins the chassis, techs add a combination of 50-mm woven roving strips, creating an egg-shaped crushable crumple zone, which transitions into the stainless-steel chassis frame member.

Flanges and other hardware are bonded into parts during layup. Panels are cured in a paint-spray booth for 4 hours at 70°C (no vacuum is used). After demolding and degreasing, a polyester spray filler (Lesanol from Akzo Nobel N.V., Abingdon, Oxfordshire, UK) is used to smooth out surface imperfections in the dry-sanded gel coat, and then inner and outer panels are bonded together using a methacrylate adhesive (two-part, rapid-cure MMA 130 from Alsco Ltd., Swindon, Wiltshire, UK) to form a "double skin." Next, parts are primed with a two-part system and the B-surface is painted (also an AkzoNobel Lesanol grade), then panels are adhesively bonded to the chassis in 24 locations, using top-hat sections. Finally, A-surfaces are painted. Where road noise could intrude, expanded foam is used inside structures, such as around wheel wells and boot/trunk liners. Where shock absorption is important, panels are both bonded and riveted in place.

Bevan acknowledges there are faster ways to make autobody panels, but points out that hand layup supports more employment in the Norfolk area. "Besides, if we sprayed our material, we'd be resin rich, and that would tend to crack more," he adds. "We're very careful not to use too much resin. Plus, hand layup gives us a chance to do things more like a GT3 [Cup Grand Touring] race car."

The resulting *Iceni* isn't just beautiful to look at and green to drive, it's also a force on the track. Last year, the car practiced against British and Italian supercars at the UK's Silverstone race track (Towcester, Northhamptonshire, UK) and did quite well, and this year it has already out-clocked a *McLaren P41* GT Cup car (McLaren Automotive, Woking, Surrey, UK), driving the whole two hours on 52L of fuel, without a single pit stop to refill — what Bevan calls "very grownup, responsible racing." A significant aspect of that maturity is the car's zero (net) carbon footprint, a benefit of its capacity for burning *bio*-diesel fuel (see the Side Story titled "Torque-multiplication: A Euro 7-ready *diesel* supercar?" on p. 36).

What's next?

Trident Motors officially rolled out the *Iceni* convertible and *Iceni Magna* late this spring and started taking orders and building vehicles. The manufacturer's suggested retail price for either model starts at £96,000/US$148,500. An "estate" model (sedan with extended roof) called the *Iceni Venturer*, was set for summer, and a true rear-wheel-drive supercar to compete with the aforementioned Roman invaders is planned for fall. Meanwhile, Trident is working on prototype military vehicles for the United Nations and the North Atlantic Treaty Organization. Next year, the company plans to begin producing left-hand-drive *Icenis* in Moraine, OH, US for the North American market. For those who love to drive (fast) *and* love the planet, there's finally one car in which a driver can find power, performance *and* fuel economy in a sleek, substantial composite package in almost *any* color … something Henry Ford, Sr. couldn't have anticipated. CW

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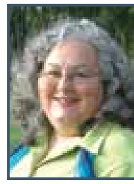

ABOUT THE AUTHOR
Contributing writer Peggy Malnati covers the automotive and infrastructure beats for *CW* and provides communications services for plastics- and composites-industry clients.
peggy@compositesworld.com

Composites Events

July 12-18, 2015 — Chengdu, China
ICCE-23, 23rd Int'l Conference on Composites and Nano Engineering
www.icce-nano.org

July 19-24, 2015 — Copenhagen, Denmark
ICCM 20 - 20th Int'l Conference on Composite Materials
www.iccm20.org

Aug. 17-20, 2015 — Edmonton, AB, Canada
CANCOM 2015
cancom2015.org

Sept. 8-10, 2015 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
www.speautomotive.com/comp.htm

Sept. 9-11, 2015 — Toulouse, France
2015 Int'l Conference on Lightning and Static Electricity (ICOLSE)
www.icolse2015.org

Sept. 9-11, 2015 — Cambridge, UK
ACIC 2015 – 7th Biennial Conference on Advanced Composites in Construction
www.acic-conference.com

Sept. 14-16, 2015 — Toulouse, France
SpeedNews 16th Annual Aviation Industry Suppliers Conference
www.speednews.com/all/conference

Sept. 15-17, 2015 — Louisville, KY, US
IBEX 2015
www.ibexshow.com

Sept. 15-17, 2015 — Amiens, France
SAMPE Europe Conference 2015
www.sampe-europe.org

Sept. 15-18, 2015 — Husum, Germany
HUSUM Wind 2015
www.husumwind.com/content/en/start/welcome-2015.php

Sept. 21-22, 2015 — Stuttgart, Germany
1st Int'l Composites Congress (ICC)
www.avk-tv.de/events.php?page=&year=2015&month=09

Sept. 22-23, 2015 — Boston, MA, US
JEC Forums 2015
www.jeccomposites.com/events/jec-forums-boston-2015

Sept. 22-24, 2015 — Stuttgart, Germany
Composites Europe
www.composites-europe.com/startseite_1.html?sprache=englisch

Sept. 22-24, 2015 — Seattle, WA, US
SAE 2015 AeroTech Congress and Exhibition
www.sae.org/events/atc

Oct. 5-7, 2015 — Orlando, FL, US
2015 Polyurethanes Technical Conference
polyurethane.americanchemistry.com/Polyurethanes-Technical-Conference

Oct. 20-21, 2015 — Knoxville, TN, US
Additive Manufacturing 2015
www.additivemanufacturinginsight.com/conferences/am-workshop

Oct. 20-22, 2015 — Singapore
JEC Asia 2015
www.jeccomposites.com/events/jec-asia-2015

Oct. 26-29, 2015 — Dallas, TX, US
CAMX – The Composites and Advanced Materials Expo
www.thecamx.org

Nov. 4-5, 2015 — Birmingham, UK
Advanced Engineering UK 2015
www.advancedengineeringuk.com

Nov. 4-7, 2015 — Sao Paulo, Brazil
Compocity 2015
www.almaco.org.br/compocity/2015

Nov. 12-14, 2015 — Istanbul, Turkey
PUTECH Eurasia/Eurasian Composites Show
www.eurasiancomposites.com

Nov. 17-19, 2015 — Seville, Spain
2nd Aerospace Structural Impact Dynamics Int'l Conference
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Composite engine piston cylinder housings

Phenolic BMC could replace aluminum in cars/motorcycles


Source | SBHPP

By the year 2020, piston cylinder housings molded from polymer composites will be introduced into passenger car and motorcycle engines, replacing the aluminum components currently in use. That's the prediction from SBHPP High Performance Plastics, a business unit of Sumitomo Bakelite Co. Ltd. (Ghent, Belgium, and Tokyo, Japan). Specifically, SBHPP has researched injection molded cylinder housings made with its glass fiber-reinforced phenolic bulk molding compound (BMC), and claims it can deliver the same performance as die-cast aluminum parts along with significant reductions in weight, engine noise and heat radiation.

SBHPP recently cooperated with the Fraunhofer Project Group – New Drive Systems (Karlsruhe, Germany) to mold a proof-of-concept composite cylinder casing for a single-cylinder 650-cc engine. A 55% glass fiber-reinforced phenolic resin was comolded with integrated inserts and a cylinder liner of aluminum (a heat-conductive liner will be needed with a BMC casing in a liquid-cooled engine, to disperse combustion heat). The part was produced in an optimized injection molding process developed with Fraunhofer, in a part cycle time of 90 seconds.

Thermosensors mounted on the exhaust, drive and inlet sides of the composite part all showed a significantly lower temperature during engine operation than sensors on the reference aluminum housing. Plus, the composite casing was 20% lighter, and acoustic tests confirmed it also greatly reduced engine noise. The project also showed approximately 10% lower manufacturing costs for a production run of up to 30,000 parts per year; for higher production volumes, the estimated cost reduction can be even more significant, claims SBHPP.

Hendrik De Keyser, marketing and technology officer at SBHPP, notes that weight reduction has become a primary focus for auto manufacturers under increasing pressure to improve fuel economy and reduce emissions. He cites lifecycle assessments that show the environmental impact of phenolic composite components over their entire lifetime is lower than that of aluminum alternatives.

SBHPP is marketing the concept to engine suppliers and automotive OEMs and aims, ultimately, to introduce an all-composite engine. "In 3-5 years' time composite cylinder housings will be a reality," adds De Keyser.

SAMPE 2015 Product Showcase

A small sampling of what *CW* saw in Baltimore (see SAMPE Conference coverage in "CW Trends," on p. 14).

» FIBER-REINFORCED THERMOPLASTICS

Chopped carbon fiber/ thermoplastic prepreg

New at the **Web Industries** (Marlborough, MA, US) booth: A high-quality, chopped carbon fiber/thermoplastic prepreg, available with PA 6, PEEK or PEKK resin. This high-precision, formatted thermoplastic chop is available to compression molders in widths and lengths matched to specification-driven needs. Composite part manufacturers can use these chopped materials in high-performance compression molding of net shapes, to reduce weight and cost compared to machined and assembled metal designs. Web Industries says the product eliminates the need for fabricators to invest in non-core assets to support market growth.

www.webindustries.com

» PRODUCTION MANAGEMENT SOFTWARE

Wi-fi sensor-based data collection

ZyynTek (a division of EmergenTek, South Jordan, UT, US) has developed a turnkey wi-fi sensor-based data collection system for cleanroom and factory-floor process control. Its small sensors can be programmed to collect critical data that the user desires, such as temperature and humidity, open doors, differential pressure and more. The sensors are then deployed at key locations, and the data is automatically collected. The data is accessible by mobile phone or iPad, and also can be sent to a computer where it is logged and archived in a report format. Sensors have a one-year battery life, and the monitoring system reportedly can save significant time for inspectors, because they eliminate manual monitoring and clipboard logging.

www.zyyntek.com

» MOLD TOOLING MATERIALS

Epoxy tooling board for masters/molds

Trelleborg Advanced Engineering and Materials (Boston, MA, US) showed its high-performance epoxy tooling materials for aerospace, electronics and industrial markets, as well as adhesives, sealers and pastes. A range of tooling board products for master models and molds were on display, manufactured using trademarked Eccospheres made in-house at its Boston factory. Its recently launched high-gloss mold and tool sealer, ES930, has been specially formulated to seal all types of substrates, has low odor and a quick cure, and can be used with all composite materials, including prepreg and dry fabrics in infusion processing. A new release agent, ER950, is specially formulated to work with all epoxy tooling materials, is easy to apply and provides a superior finish. Also at the stand, Trelleborg Offshore & Construction representative Todd Grahn described a new buoyancy technology for ultra-deep offshore drill operations, using Eccospheres in an epoxy matrix, which can withstand very high pressures. The new technology will be officially released to the market next year.
www.trelleborg.com/en/Advanced-Engineering-Materials

» FIBER-REINFORCED THERMOPLASTICS

Pre-consolidated organosheet

SGL Group (Wiesbaden, Germany) is expanding its SIGRAFIL C T50-4.0/240-T140 carbon fiber product line, optimized for thermoplastics, with the addition of organic (thermoplastic) sheets reinforced with carbon *and* glass fibers. SGL notes that components made from the organic sheets can be shaped into almost any final-product geometry and also can be repaired and recycled. Two standard sizes are available, but SGL Group also offers individualized laminate structures, which can be customer-specified in terms of fiber orientation, textile architectures and wall thickness.
www.sglgroup.com

» DESIGN & SIMULATION SOFTWARE

Updated, adaptable optimization program

Collier Research Corp. (Newport News, VA, US) featured the latest version of its signature design, analysis and optimization software, HyperSizer. Version 7 is reportedly easier to learn and use, has a new menu system that requires less user input, and is computationally faster. HyperSizer is designed to work with CAD, a finite element modeler or FEA to achieve a realistic, fully optimized and easily manufactured design that is optimized for weight reduction. The company says that design cycle times are reduced yet enable evaluation of millions of panel and beam cross sections, without remeshing. In addition, structure certification is faster, because hundreds of industry-standard failure methods can be analyzed quickly. Further, complete documentation is produced for test data validation and to satisfy FAA certification document requirements.
www.hypersizer.com

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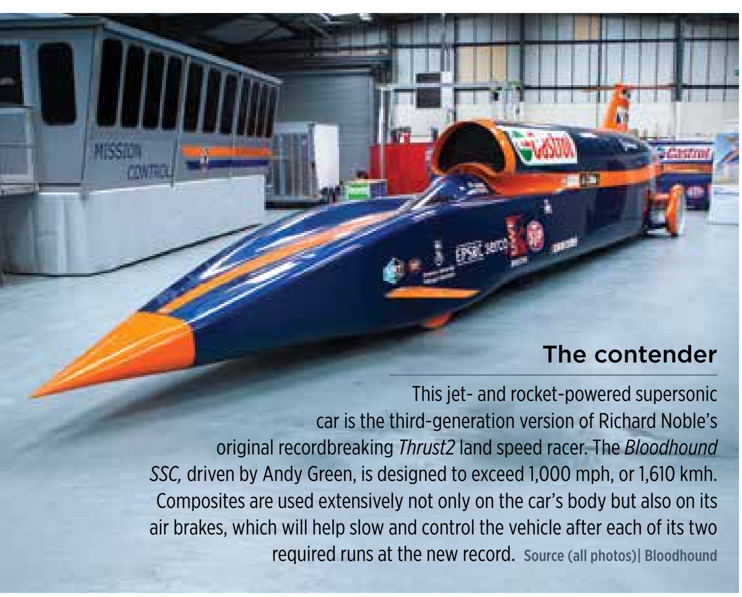
Composite air brakes: Stopping the world's fastest car

CFRP sandwich structures are a key element of deceleration in the *Bloodhound SSC* rocket-powered racer's two-run attempt at resetting the land speed record.

By Sara Black / Technical Editor

» A tiny French *Jeantaud Duc* electric vehicle set the first wheeled-vehicle land speed record of 63 kmh, in 1898. One hundred years later, Richard Noble drove the *Thrust SSC* jet-powered vehicle to the first supersonic and still unbroken record of 1,227.985 kmh, in Black Rock Desert, in the US state of Nevada. Now, Noble and a team of engineers aim to smash his own record in pursuit of a much more ambitious goal: 1610 kmh, the mythic land speed record milestone of 1,000 mph. The attempt will be made in 2016 at Hakskeen Pan, South Africa, in a third-generation supersonic jet-/rocket-powered vehicle, dubbed the *Bloodhound SSC.*

"This project represents most aspects of what would be seen in a major aerospace program," says Tim Edwards, the engineer who oversaw a team within Atkins' (Bristol, UK) aerospace business division, which was responsible for structural analysis of the vehicle's composite elements as consultants to the *Bloodhound* engineering team. "We were engaged by *Bloodhound* because of our experience in the analysis of laminated composite structures — especially for aerospace applications." Edwards' team also helped interpret loads from the whole-vehicle finite element model and select analysis methods for specific components.



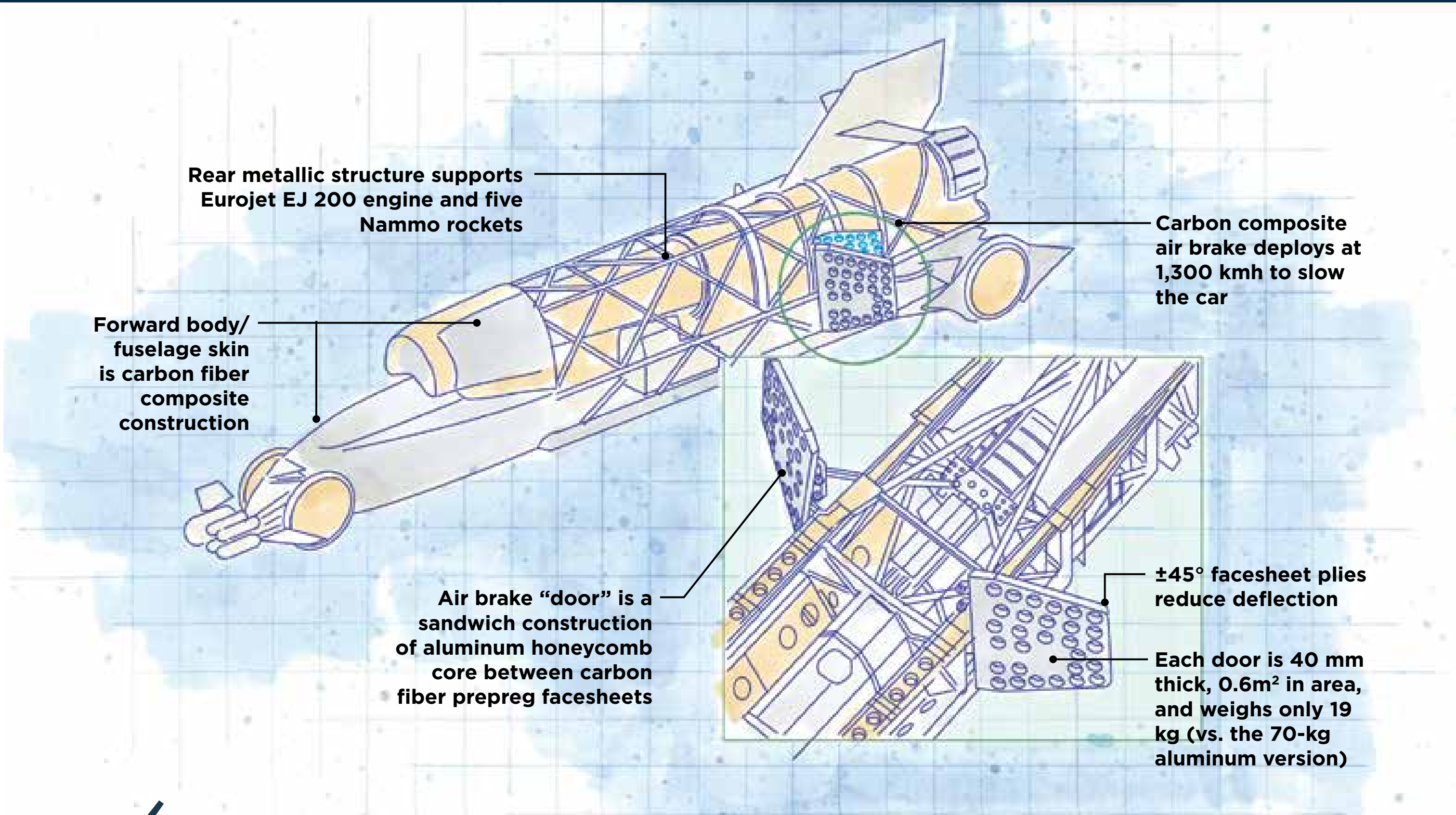
The contender

This jet- and rocket-powered supersonic car is the third-generation version of Richard Noble's original recordbreaking *Thrust2* land speed racer. The *Bloodhound SSC,* driven by Andy Green, is designed to exceed 1,000 mph, or 1,610 kmh. Composites are used extensively not only on the car's body but also on its air brakes, which will help slow and control the vehicle after each of its two required runs at the new record. Source (all photos)| Bloodhound

Although the car's sole purpose is to achieve extreme speed, significant constraints dictated its design. Lightweight carbon composites could be used to create the slender yet highly curved aerodynamic forward body shell and engine intake, but heavier aluminum/titanium construction was required rearward to withstand the elevated rocket exhaust temperatures. Because the 7.5-MT, 13.5m-long car will be shipped to South Africa for the record run, the vehicle had to include a mid-length joint to permit disassembly for easier handling. Most important, rules require that *two* runs must be made in opposing directions (recorded speed is the *average* of the two) *within one hour*, so the car must be stopped, refueled and turned around very quickly. "Acceleration, deceleration and refueling time are critical, and no time can be wasted in slowing down," Edwards points out, "So, in addition to powerful propulsion, *braking* is a key element."

SLOWING A ROCKET

Braking won't be easy: Powered by the same type Rolls-Royce EJ200 jet engine used in the EuroFighter *Typhoon* aircraft *and* five rocket engines from Nammo (a Jaguar 550-hp V8 engine will be used just to pump liquid rocket fuel!), the *Bloodhound* will cover the 1.6 km-long record segment in a mere 3.6 seconds. To stop it within the confines of the 19.3-km lake bed test track, *Bloodhound's* engineers will rely on huge aerodynamic drag to slow the car to about 1,300 kmh. Then, two slaved, ram-actuated airbrakes, one on each side of the car, will open outward like doors from the craft's body. Similar to aircraft speed brakes, they are designed to slow the car to 300 kmh, when wheel brakes will engage. Edwards explains that the positions of the airbrakes, their actuator arms and door hinges were dictated by the available space inside the vehicle (see drawing, p. 47), the lack of which meant that each door could be no larger in area than $0.6m^2$ and no more than 50 mm thick. "We were tasked to consider a door machined from a single piece of aluminum vs. a composite door," says Edwards. Perforations in the doors will break up the airflow, but ensure that oscillatory loading on the rear suspension assembly, located immediately behind the airbrakes, will be minimized. "To avoid any possibility of the natural frequency of the doors coinciding with the frequency of vortex shedding effects from the car's body," he adds, "any material had to exhibit a minimum first natural frequency of at least 45 Hz." Further, the design must withstand aerodynamic loading when deployed at speed, without excessive deflection or



DESIGN RESULTS | **Carbon Fiber Composite Air Brakes for *Bloodhound SSC* Supersonic Racecar**

- FEA modeling of aluminum vs. composite air brake panels showed that composites offered better frequency response, and thus, less vibration when deployed.
- FEA and computation fluid dynamics (CFD) models showed bias plies (±45°) would reduce bending and deflection in the composite air brakes.
- The composite sandwich-construction air brake "door" panel is one quarter the weight of an aluminum version, yet offers comparable braking power.

Illustration / **Karl Reque**

flapping. Given these parameters, a modeling and design effort was carried out to determine the best material choice. A finite element analysis (FEA) model of the air brake door was constructed — using HyperMesh and HyperWorks from Altair Engineering Inc. (Troy, MI, US) — by using the mid-plane surface from the air brake door CAD model and creating a 2D element mesh on that surface, explains Edwards. "Mid-plane models were also created in a similar way for each of the four hinge attachments in order to accurately represent the stiffness of the entire assembly during modal analysis."

Next, aerodynamic loading on the doors was derived from the results of computational fluid dynamics (CFD) analysis, using Fluent, a software package that is part of the ANSYS numerical simulation package from CAE Associates Inc. (Middlebury, CT, US). (CFD with Fluent also played a big role in other aspects of the vehicle, and influenced the design of the front wheels, the shape of the nose, the jet engine intake, rear wheel fairings and the wing.) For the airbrakes, Fluent used five combinations of door position and velocity, beginning with the conservative assumption that the door would deploy at the car's top speed of 450 m/sec, to calculate air-pressure loads to input to the FEA model. Beyond solid aluminum plate, modeled materials were sandwich constructions, with skins made from Cytec Aerospace Materials' (Tempe, AZ, US) unidirectional MTM49-3 carbon prepreg tape, featuring high-modulus M46J carbon fibers from Toray Industries (Tokyo, Japan), and a Cytec MTM49-3 woven 2x2 twill prepreg made with Toray T700 fibers. Core material was an aluminum honeycomb from Hexcel (Stamford, CT, US). "For the material analyses, the 0° fiber direction was aligned perpendicular to the door hinge line in the plane of the air brake door," says Edwards. He used standard bolt group theory to determine the loads at the three metallic hinge positions, and spread the loads from the hinges to the doors with the use of "spider" nodes within the FEA model, so named because of the way the nodes are connected to each other to simulate load transfer.

DEFLECTION vs. WEIGHT vs. VIBRATION

Atkins compared a number of sandwich panel configurations, in terms of skin and core thickness, with the solid aluminum (Figs, 1 & 2, p. 48). "Early analysis showed that in the composite designs, the maximum deflection was occurring at the corner furthest from the actuator attachment," says Edwards, "We had to increase overall stiffness, and the potential composite layups were altered to include a greater number of ±45° plies." This strategy was confirmed by the modal analyses (a study of how the doors would react under vibrational excitation), using the Radioss solver in Altair's HyperWorks »

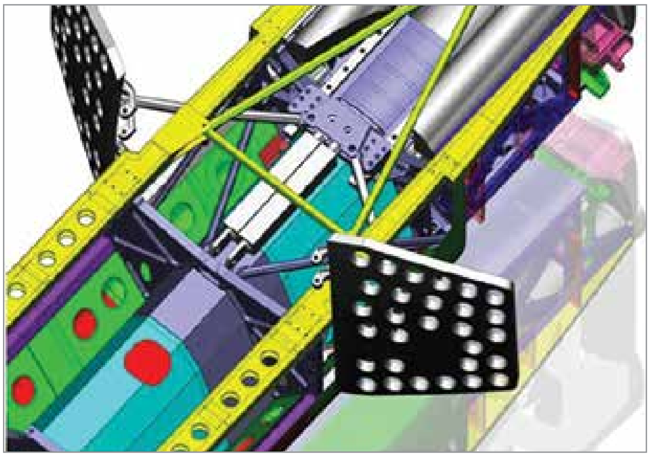


FIG. 1: Deployed air brakes

This CAD drawing of the *Bloodhound's* ram-actuated air brakes shows the brake panels in the deployed position. After air drag brings the vehicle's speed down from (it is hoped) record-setting levels, the brakes are designed to deploy and slow the car in the range from 1,300 to 300 kmh, at which point the car's wheel brakes will be engaged.

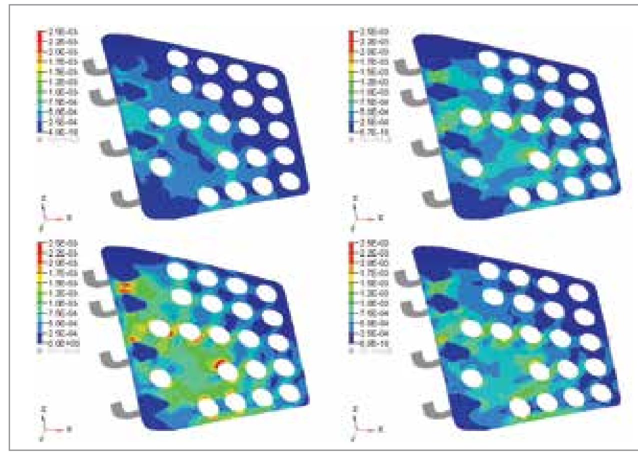


FIG. 2: Sandwich construction options

Von-Mises stresses are shown for the four airbrake designs, clockwise from top left, 40-mm-thick aluminum, sandwich panel with uni carbon tape face sheets and 38-mm core, sandwich panel with 7-mm-thick facesheets of woven carbon prepreg and 36-mm-thick core, and (lower left) sandwich panel with 7-mm-thick facesheets that combine uni and woven material with a 38-mm-thick core.

software package. The first vibrational mode was torsional, meaning that the door's trailing edge would have a tendency to twist relative to the hinge line. This reinforced Edward's conclusion that more bias plies were a must.

The Atkins team ultimately developed four door designs: 1) a single aluminum piece, 40 mm thick; 2) a composite sandwich panel with 6-mm UD facesheets and 38-mm-thick core; 3) a composite sandwich with 7-mm woven prepreg facesheets with 36-mm-thick core; and 4) a composite sandwich with 7-mm-thick facesheets made up of a combination of UD tapes and woven fabric prepreg, with a 38-mm-thick core. The 7-mm facesheet requires an approximate 28-ply layup.

Edwards makes clear that the aluminum design exhibited the smallest maximum deflection. But, in addition to weighing almost *four times* more than the composite solution (70 kg vs. 19 kg), it exhibited a much lower first natural frequency (61 Hz), indicating a propensity for undesirable vibration when deployed. Fig. 2 shows the four designs in terms of maximum strain results; Edwards points out that while stress concentrations occur at hole edges closest to the actuator arm, the use of ±45° plies increased the first natural frequency and reduced overall strain values. "We conducted Tsai-Hill ply failure analysis in the FEA solver to ensure that there were no predicted failures in the higher strain regions," he says, concluding, "The cored composite is the most structurally efficient design." Edwards notes that Bloodhound engineers will make the final selection from among the three cored designs.

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The *Bloodhound SSC* Web site has an extraordinary amount of information, including all CAD drawings, for the vehicle and its systems | short.compositesworld.com/BSSC-CAD

AN OPPORTUNITY FOR STEM STUDENTS

The impending run at the 1,000-mph threshold has captured the imagination of thousands of followers. Noble is keen to lift awareness in UK schools and stimulate student interest, using a wide range of math and engineering problems related to the car's design. In fact, *Bloodhound* team members regularly lecture in schools, and post math questions online about vehicle systems. When Edwards visited Seattle to deliver a presentation at the SAMPE conference in May 2014, he also gave a talk on propulsion to students at nearby Raisbeck Aviation High School. And student teams in the UK are even building rocket-powered scale models of the *Bloodhound*.

Provided that Hakskeen Pan is dry and ready, the *Bloodhound's* first high-speed runs could commence late this year. Edwards says these will take the car up to around 800 mph, which in itself would be a world record. Low-speed UK runway tests are scheduled for earlier in 2015. The full-on "1,000" run likely will occur sometime in 2016. *Bloodhound's* driver, Andy Green, has said in his monthly diary, "It's easy to forget the most important part of building the world's first 1,000-mph car: Getting to 1,000 mph safely is not just about technology, it's about engineering expertise…" The world will be watching this engineering marvel in its record quest. CW

ABOUT THE AUTHOR

Sara Black is *CW's* technical editor and has served on the *CW* staff for 17 years.
sara@compositesworld.com